Dynamic Natural Monopoly Regulation: Time Inconsistency, Asymmetric Information, and Political Environments

Claire S.H. Lim[*] Ali Yurukoglu[†]
Cornell University Stanford University [‡]

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Abstract

This paper quantitatively assesses time inconsistency, asymmetric information, and political ideology in monopoly regulation of electricity distribution companies. Empirically, we estimate that (1) there is under-investment in electricity distribution capital to reduce power outages, (2) more conservative political environments have higher regulated returns, and (3) more conservative political environments have more electricity lost in distribution. We explain these empirical results with an estimated dynamic game model of utility regulation featuring investment and asymmetric information. We quantify the value of regulatory commitment in inducing more investment. Conservative regulators improve welfare losses due to time inconsistency, but worsen losses from asymmetric information.

Keywords: Regulation, Natural Monopoly, Electricity, Political Environment, Dynamic Game Estimation

JEL Classification: D72, D78, L43, L94

1 Introduction

In macroeconomics, public finance, and industrial organization and regulation, policy makers suffer from the inability to credibly commit to future policies (Coase (1972), Kydland and Prescott (1977)) and from the existence of information that is privately known to the agents subject to their policies (Mirrlees (1971), Baron and Myerson (1982)). These two obstacles, "time inconsistency" and "asymmetric information," make it difficult, if not impossible, for regulation to achieve

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[*] Department of Economics, 404 Uris Hall, Ithaca, NY 14853 (e-mail: clairelim@cornell.edu)

[†] Graduate School of Business, 655 Knight Way, Stanford, CA 94305 (e-mail: Yurukoglu_Ali@gsb.stanford.edu)

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first-best policies. This paper analyzes these two forces and their interaction with the political environment in the context of regulating the U.S. electricity distribution industry, a natural monopoly sector with yearly revenues of $320 billion.

The time inconsistency problem in this context is the possibility of regulatory hold-up in rate-of-return regulation. The regulator would like to commit to a fair return on irreversible investments *ex ante*. Once the investments are sunk, the regulator is tempted to adjudicate a lower return than promised (Baron and Besanko (1987), Gilbert and Newbery (1994), Lewis and Sappington (1991)).[1] The utility realizes this dynamic, resulting in under-investment by the regulated utility.[2] The asymmetric information problem in this context is moral hazard: the utility can take costly actions that improve productivity, but the regulator can not directly measure the extent of these actions (Baron and Myerson (1982), Laffont and Tirole (1993) and Armstrong and Sappington (2007)).[3]

These two forces interact with the political environment. A central theme of this paper is that regulatory environments which place a higher weight on utility profits vis-à-vis consumer surplus grant higher rates of return, which encourages more investment, alleviating inefficiencies due to time inconsistency and the fear of regulatory hold-up. However, these regulatory environments engage in less intense auditing of the utility's unobserved effort choices, leading to more inefficiency in production, exacerbating the problem of asymmetric information.

The core empirical evidence supporting this formulation is twofold. First, we estimate that there is under-investment in electricity distribution capital in the U.S. To do so, we estimate the costs of improving reliability by capital investment. We combine those estimates with surveyed values of reliability. At current mean capital levels, the benefit of investment in reducing power outages exceeds the costs. Second, regulated rates of return are higher, but measures of productivity are lower with more conservative regulatory environments. We measure the ideology of the regulatory environment using both cross-sectional variation in how a state's U.S. Congressmen vote, and within-state time variation in the party affiliation of state regulatory commissioners. Both results hold using either source of variation.

We explain these core empirical findings with a dynamic game theoretic model of the regulator-utility interaction. The utility invests in capital, and exerts effort that affects productivity to maximize its firm value. The regulator chooses a return on the utility's capital and a degree of auditing of the utility's effort choice to maximize a weighted average of utility profits and consumer surplus. The regulator can not commit to future policies, but has a costly auditing technology. We use

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[1] See also Section 3.4.1 of Armstrong and Sappington (2007) for more references and discussion of limited commitment, regulation, and expropriation of sunk investments.

[2] In our context, under-investment manifests itself as an aging infrastructure prone to too many power outages.

[3] Adverse selection is also at play in the literature on natural monopoly regulation. This paper focuses on moral hazard.

the solution concept of Markov Perfect Equilibrium. Markov perfection in the equilibrium notion implies a time-inconsistency problem for the regulator which in turn implies socially sub-optimal investment levels by the utility.

We estimate the model's parameters using a two-step estimation procedure following Bajari et al. (2007) and Pakes et al. (2007). Given the core empirical results and the model's comparative statics, we estimate that more conservative political environments place relatively more weight on utility profits than less conservative political environments. More weight on utility profits can be good for social welfare because it leads to stronger investment incentives, which in turn mitigates the time inconsistency problem. However, this effect must be traded-off with the tendency for lax auditing which reduces managerial effort, productivity, and social welfare.

We use the estimated parameters to simulate appropriate rules and design of institutions to increase investment incentives and balance the tension between investment incentives and effort provision. We counterfactually simulate outcomes when (1) the regulator can commit to future rates of return, (2) there are minimum auditing requirements for the regulator, and (3) the regulatory board must maintain a minimum level of minority representation. In the first counterfactual with commitment, we find that regulators would like to substantially increase rates of return to provide incentives for capital investment. This result is consistent with recent efforts by some state legislatures to bypass the traditional regulatory process and legislate more investment in electricity distribution capital. This result also implies that tilting the regulatory commission towards conservatives, analogous to the idea in Rogoff (1985) for central bankers, can mitigate the time inconsistency problem. However, such a policy would be enhanced by minimum auditing requirements. Minority representation requirements reduce uncertainty for the utility and variance in investment rates, but have quantitatively weak effects on investment and productivity levels.

This paper contributes to literatures in both industrial organization and political economy. Within industrial organization and regulation, the closest papers are Timmins (2002), Wolak (1994), Gagnepain and Ivaldi (2002), and Abito (2013). Timmins (2002) estimates regulator preferences in a dynamic model of a municipal water utility. In that setting, the regulator controls the utility directly which led to a theoretical formulation of a single-agent decision problem. By contrast, this paper studies a dynamic game where there is a strategic interaction between the regulator and utility. Wolak (1994) pioneered the empirical study of the regulator-utility strategic interaction in static settings with asymmetric information. More recently, Gagnepain and Ivaldi (2002) and Abito (2013) use static models of regulator-utility asymmetric information to study transportation service and environmental regulation of power generation, respectively. This paper adds an investment problem in parallel to the asymmetric information. Adding investment brings issues of commitment and dynamic decisions in regulation into focus. Lyon and Mayo (2005) study the possibility of regulatory hold-up in power generation.[4] Levy and Spiller (1994) present a series of case studies on regulation of telecommunications firms, mostly in developing countries. They conclude that "without... commitment long-term investment will not take place, [and] that achieving such commitment may require inflexible regulatory regimes." Our paper is also related to static production function estimates for electricity distribution such as Growitsch et al. (2009) and Nillesen and Pollitt (2011). On the political economy side, the most closely related papers are Besley and Coate (2003) and Leaver (2009). Besley and Coate (2003) compare electricity pricing under appointed and elected regulators. Leaver (2009) analyzes how regulators' desire to avoid public criticisms lead them to behave inefficiently in rate reviews.

More broadly, economic regulation is an important feature of banking, health insurance, water, waste management, and natural gas delivery. Regulators in these sectors are appointed by elected officials or elected themselves, whether they be a member of the Federal Reserve Board[5], a state insurance commissioner, or a state public utility commissioner. Therefore, different political environments can give rise to regulators that make systematically different decisions which ultimately determine industry outcomes as we find in electric power distribution.

Finally, our analysis has two implications for environmental policy. First, investments in electricity distribution are necessary to accommodate new technologies such as smart meters and distributed generation. Our findings quantify a fundamental obstacle to incentivizing investment which is the fear of regulatory hold-up. Second, our findings on energy loss, which we find to vary significantly with the political environment, are also important for minimizing environmental damages. Energy that is lost through the distribution system needlessly contributes to pollution without any consumption benefit. We find that significant decreases in energy loss are potentially possible through more intense regulation.[6]

2 Institutional Background, Data, and Preliminary Analysis

We first describe the electric power distribution industry and its regulation. Then, we describe the data sets we use and key summary statistics. Next, we present the empirical results on the relationships between rate of return and political ideology as well as efficiency as measured by energy lost during transmission and distribution with political ideology. We also present evidence on the relationships between investment and rates of return. Finally, we present the estimated

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[4] They conclude that observed capital disallowances during their time period do not reflect regulatory hold-up. However, fear of regulatory hold-up can be present even without observing disallowances, because the utility is forward looking.

[5] The interaction of asymmetric information and time inconsistency in monetary policy has been explored theoretically in Athey et al. (2005), though the economic environment is quite different than in this paper.

[6] A similar issue exists for natural gas leakage, in which the methane that leaks in delivery, analogous to energy loss, is a potent greenhouse gas, and the regulatory environment is nearly identical to that of electric power distribution.

relationships between reliability and capital levels.

2.1 Institutional Background

The electricity industry supply chain consists of three levels: generation, transmission, and distribution.[7] This paper focuses on distribution. Distribution is the final leg by which electricity is delivered locally to residences and business.[8] Generation of electricity has been deregulated in many countries and U.S. states. Distribution is universally considered a natural monopoly. Distribution activities are regulated in the U.S. by state "Public Utility Commissions" (PUC's)[9]. The commissions' mandates are to ensure reliable and least cost delivery of electricity to end users.

The regulatory process centers on PUC's and utilities engaging in periodic "rate cases." A rate case is a quasi-judicial process via which the PUC determines the prices a utility will charge until its next rate case. The rate case can also serve as an informal venue for suggesting future behavior and discussing past behavior. In practice, regulation of electricity distribution in the U.S. is a hybrid of the theoretical extremes of rate-of-return (or cost-of-service) regulation and price cap regulation. Under rate-of-return regulation, a utility is granted rates that earn it a fair rate of return on its capital and to recover its operating costs. Under price cap regulation, a utility's prices are capped indefinitely. PUC's in the U.S. have converged on a system of price cap regulation with periodic resetting to reflect changes in cost of service as detailed in Joskow (2007).

This model of regulation requires the regulator to determine the utility's revenue requirement. The price cap is then set to generate the revenue requirement. The revenue requirement must be high enough so that the utility can recover its prudent operating costs and earn a rate of return on its capital that is in line with other investments of similar risk (U.S. Supreme Court (1944)). This requirement is vague enough that regulator discretion can result in variant outcomes for the same utility. Indeed, rate cases are prolonged affairs where the utility, regulator, and third parties present evidence and arguments to influence the ultimate revenue requirement. Furthermore, the regulator can disallow capital investments that do not meet a standard of "used and useful."[10]

As a preview, our model replicates much, but not all, of the basic structure of the regulatory process in U.S. electricity distribution. Regulators will choose a rate of return and some level of auditing to determine a revenue requirement. The utility will choose its investment and productivity levels strategically. We will, for the sake of tractability and computation, abstract away from

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[7] This is a common simplification of the industry. Distribution can be further partitioned into true distribution and retail activities. Generation often uses fuels acquired from mines or wells, another level in the production chain.

[8] Transmission encompasses the delivery of electricity from generation plant to distribution substation. Transmission is similar to distribution in that it involves moving electricity from a source to a target. Transmission operates over longer distances and at higher voltages.

[9] PUC's are also known as "Public Service Commissions," "State Utility Boards", or "Commerce Commissions".

[10] The "used and useful" principle means that capital assets must be physically used and useful to current ratepayers before those ratepayers can be asked to pay the costs associated with them.

some other features of the actual regulator-utility dynamic relationship. We will not allow the regulator to disallow capital expenses directly, though the regulator will be allowed to adjudicate rates of return below the utility's discount rate. We will ignore equilibrium in the financing market and capital structure. We will assume that a rate case happens every period. In reality, rate cases are less frequent.[11] Finally, we will ignore terms of rate case settlements concerning prescriptions for specific investments, clauses that stipulate a minimum amount of time until the next rate case, an allocation of tariffs across residential, commercial, industrial, and transportation customer classes, and special considerations for low income or elderly consumers. Lowell E. Alt (2006) is a thorough reference regarding the details of the rate setting process in the U.S.

2.2 Data

Characteristics of the Political Environment and Regulators: The data on the political environment consists of four components: two measures of political ideology, campaign financing rule, and the availability of ballot propositions. All these variables are measured at the state-level, and measures of political ideology also vary over time. For measures of political ideology, we use DW-NOMINATE score (henceforth "Nominate score") developed by Keith T. Poole and Howard Rosenthal (see Poole and Rosenthal (2000)). They analyze congressmen's behavior in roll-call votes on bills, and estimate a random utility model in which a vote is determined by their position on ideological spectra and random taste shocks. Nominate score is the estimated ideological position of each congressman in each congress (two-year period).[12] We aggregate congressmen's Nominate score for each state-congress, separately for the Senate and the House of Representatives. This yields two measures of political ideology, one for each chamber. The value of these measures increase in the degree of conservatism.

For campaign financing rule, we focus on whether the state places no restrictions on the amount of campaign donations from corporations to electoral candidates. We construct a dummy variable,

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[11] Their timing is also endogenous in that either the utility or regulator can initiate a rate case.

[12] DW-NOMINATE is an acronym for "Dynamic, Weighted, Nominal Three-Step Estimation". It is one of the most classical multidimensional scaling methods in political science that are used to estimate politicians' ideology based on their votes on bills. It is based on several key assumptions. First, a politician's voting behavior can be projected on two-dimensional coordinates. Second, he has a bell-shaped utility function, the peak of which represents his position on the coordinates. Third, his vote on a bill is determined by his position relative to the position of the bill, and a random component of his utility for the bill, which is conceptually analogous to an error term in a probit model.

There are four versions of NOMINATE score: D-NOMINATE, W-NOMINATE, Common Space Coordinates, and DW-NOMINATE. The differences are in whether the measure is comparable across time (D-NOMINATE, and DW-NOMINATE), whether the two ideological coordinates are allowed to have different weights (W-NOMINATE and DW-NOMINATE), and whether the measure is comparable across the two chambers (Common Space Coordinates). We use DW-NOMINATE, because it is the most flexible and commonly used among the four, and is also the most suitable for our purpose in that it gives information on cross-time variation. DW-NOMINATE has two coordinates – economical (e.g., taxation) and social (e.g., civil rights). We use *only the first coordinate* because Poole and Rosenthal (2000) documented that the second coordinate has been unimportant since the late twentieth century. For a more thorough description of this measure and data sources, see http://voteview.com/page2a.htm

Table 1: Summary Statistics

Variable	Mean	S.D.	Min	Max	# Obs
Panel A: Characteristics of Political Environment					
Nominate Score - House	0.1	0.29	-0.51	0.93	1127
Nominate Score - Senate	0.01	0.35	-0.61	0.76	1127
Proportion of Republicans	0.44	0.32	0	1	1145
Unlimited Campaign	0.12	0.33	0	1	49[a]
Ballot	0.47	0.5	0	1	49
Panel B: Characteristics of Public Service Commission					
Elected Regulators	0.22	0.42	0	1	49
Number of Commissioners	3.9	1.15	3	7	50
Panel C: Information on Utilities and the Industry					
Median Income of Service Area ($)	47495	12780	16882	94358	4183
Population Density of Service Area	791	2537	0	32445	4321
Total Number of Consumers	496805	759825	0	5278737	3785
Number of					
Residential Consumers	435651	670476	0	4626747	3785
Commercial Consumers	57753	87450	0	650844	3785
Industrial Consumers	2105	3839	0	45338	3785
Total Revenues ($1000)	1182338	1843352	0	12965948	3785
Revenues ($1000) from					
Residential Consumers	502338	802443	0	7025054	3785
Commercial Consumers	427656	780319	0	6596698	3785
Industrial Consumers	232891	341584	0	2888092	3785
Net Value of Distribution Plant ($1000)	1246205	1494342	-606764	12517607	3682
Average Yearly Rate of Addition to Distribution Plant between Rate Cases	0.0626	0.0171	0.016	0.1494	511
Average Yearly Rate of Net Addition to Distribution Plant between Rate Cases	0.0532	0.021	-0.0909	0.1599	511
O&M Expenses ($1000)	68600	78181	0	582669	3703
Energy Loss (Mwh)	1236999	1403590	-7486581	1.03e+07	3796
Reliability Measures					
SAIDI (minutes)	137.25	125.01	4.96	3908.85	1844
SAIFI (times)	1.48	5.69	0.08	165	1844
CAIDI (minutes)	111.21	68.09	0.72	1545	1844
Bond Rating[b]	6.9	2.3	1	18	3047
Panel D: Rate Case Outcomes					
Return on Equity (%)	11.27	1.29	8.75	16.5	729
Return on Capital (%)	9.12	1.3	5.04	14.94	729
Equity Ratio (%)	45.98	6.35	16.55	61.75	729
Rate Change Amount ($1000)	47067	114142	-430046	1201311	677

Note 1: In Panel A, the unit of observation is state-year for Nominate scores, and state for the rest. In Panel B, the unit of observation is state for whether regulators are elected, number of commissioners, and state-year for the proportion of Republicans. In Panel C, the unit of observation is utility-year, except for average yearly rate of (net and gross) addition to distribution plant between rate cases for which the unit of observation is rate case. In Panel D, the unit of observation is (multi-year) rate case.

Note 2: All the values in dollar term are in 2010 dollars.

[a] Nebraska is not included in our rate case data, and the District of Columbia is. For some variables, we have data on 49 states. For others, we have data on 49 states plus the District Columbia.

[b] Bond ratings are coded as integers varying from 1 (best) to 20 (worst). For example, ratings Aaa (AAA), Aa1(AA+), and Aa2(AA) correspond to ratings 1, 2, and 3, respectively.

Unlimited Campaign, that takes value one if the state does not restrict the amount of campaign donation. We use the information provided by the National Conference of State Legislatures.[13] As for the availability of ballot initiatives, we use the information provided by the Initiative and Referendum Institute.[14] We construct a dummy variable, *Ballot*, that takes value one if ballot proposition is available in the state.

We use the "All Commissioners Data" developed by Janice Beecher and the Institute of Public Utilities Policy Research and Education at Michigan State University to determine the party affiliation of commissioners and whether they are appointed or elected, for each state and year.[15]

Utilities and Rate Cases: We use four data sets on electric utilities: the Federal Energy Regulation Commission (FERC) Form 1 Annual Filing by Major Electric Utilities, the Energy Information Administration (EIA) Form 861 Annual Electric Power Industry report, the PA Consulting Electric Reliability database, and the Regulatory Research Associates (RRA) rate case database.

FERC Form 1 is filed yearly by utilities which exceed one million megawatt hours of annual sales in the previous three years. It details their balance sheet and cash flows on most aspects of their business. The key variables for our study are the net value of electric distribution plant, operations and maintenance expenditures of distribution, and energy loss for the years 1990-2012.

Energy loss is recorded on Form 1 on page 401(a): "Electric Energy Account." Energy loss is equal to the difference between energy purchased or generated and energy delivered. The average ratio of electricity lost through distribution and transmission to total electricity generated is about 7% in the U.S., which translates to roughly 25 billion dollars in 2011. Some amount of energy loss is unavoidable because of physics. However, the extent of losses is partially controlled by the utility. Utilities have electrical engineers who specialize in the efficient design, maintenance, and operation of power distribution systems. The configuration of the network of lines and transformers and the age and quality of transformers are controllable factors which affect energy loss.

EIA Form 861 provides data by utility and state by year on number of customers, sales, and revenues by customer class (residential, commercial, industrial, or transportation).

The PA Consulting reliability database provides reliability metrics by utility by year. We focus on the measure of System Average Interruption Duration Index (SAIDI), excluding major events.[16]

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[13] See http://www.ncsl.org/legislatures-elections/elections/campaign-contribution-limits-overview.aspx for details. In principle, we can classify campaign financing rules into finer categories using the maximum contribution allowed. We tried various finer categorizations, and they did not produce any plausible salient results. Thus, we simplified coding of campaign financing rules to binary categories and abstracted from this issue in the main analysis.

[14] See http://www.iandrinstitute.org/statewide_i%26r.htm

[15] We augmented this data with archival research on commissioners to determine their prior experience: whether they worked in the energy industry, whether they worked for the commission as a staff member, whether they worked in consumer or environmental advocacy, or in some political office such as state legislator or gubernatorial staff. We analyzed relationships between regulators' prior experience and rate case outcomes. We do not document this analysis because it did not discover any statistically significant relationships.

[16] Major event exclusions are typically for days when reliability is six standard deviations from the mean, though

SAIDI measures the average number of minutes of outage per customer-year.[17] Since SAIDI is a measure of power outage, a high value of SAIDI implies low reliability.

We acquired data on electric rate cases from Regulatory Research Associates and SNL Energy. The data is composed of total 729 cases on 144 utilities from 50 states, from 1990 to 2012. It includes four key variables on each rate case: return on equity[18], return on capital, equity ratio, and the change in revenues approved summarized in Panel D of Table 1.

We use data on utility territory weather, demographics, and terrain. For weather, we use the "Storm Events Database" from the National Weather Service. We aggregate the variables rain, snow, extreme wind, extreme cold, and tornado for a given utility territory by year. We create interactions of these variables with measurements of tree coverage, or "canopy", from the National Land Cover Database (NLCD) produced by the Multi-Resolution Land Characteristics Consortium. Finally, we use population density and median household income aggregated to utility territory from the 2000 U.S. census.

2.3 Preliminary Analysis

In this subsection, we document reduced-form relationships between our key variables: political ideology, regulated rates of return, investment, reliability, and energy loss.

2.3.1 Political Ideology and Return on Equity

We first investigate the relationship between political ideology of the state and the return on equity approved in rate cases.[19] Figure 1 shows scatter plots of return on equity and Nominate scores for

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exact definitions vary over time and across utilities.

[17] SAIDI is equal to the sum of all customer interruption durations divided by the total number of customers. We also have System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Duration Index (CAIDI). SAIFI is equal to the total number of interruptions experienced by customers divided by the number of customers, so that it does not account for duration of interruption. CAIDI is equal to SAIDI divided by SAIFI. It measures the average duration conditional on having an interruption. We use SAIDI as our default measure of reliability as this measure includes both frequency and duration across all customers.

[18] The capital used by utilities to fund investments commonly comes from three sources: the sale of common stock (equity), preferred stock and bonds (debt). The weighted-average cost of capital, where the equity ratio is the weight on equity, becomes the rate of return on capital that a utility is allowed to earn. Thus, return on capital is a function of return on equity and equity ratio. In the regressions in Section 2.3.1, we document results on return on equity, because return on capital is a noisier measure of regulators' discretion due to random variation in equity ratio.

[19] What we obtain in this analysis is a correlation rather than a precise causal relationship. However, it is reasonable to interpret our result as causal for several reasons. First, theoretically, equity ratio and bond rating are the two key factors that determine adjudication of the return on equity, and we control for them. Second, the return on equity is unlikely to influence the partisan composition of commissioners. In the states with appointed regulators, the election of governors, who subsequently appoint regulators, is determined by other factors such as taxation or education rather than electricity pricing. Even in the states with elected regulators, the election of low-profile public officials such as regulators is determined primarily by partisan tides (see Squire and Smith (1988) or Lim and Snyder (2014)). Thus, reverse causality is not a serious concern. Third, compared with political institutions such as appointment or election of regulators, political ideology is a more intrinsic characteristic of political environments. It is less likely to be driven

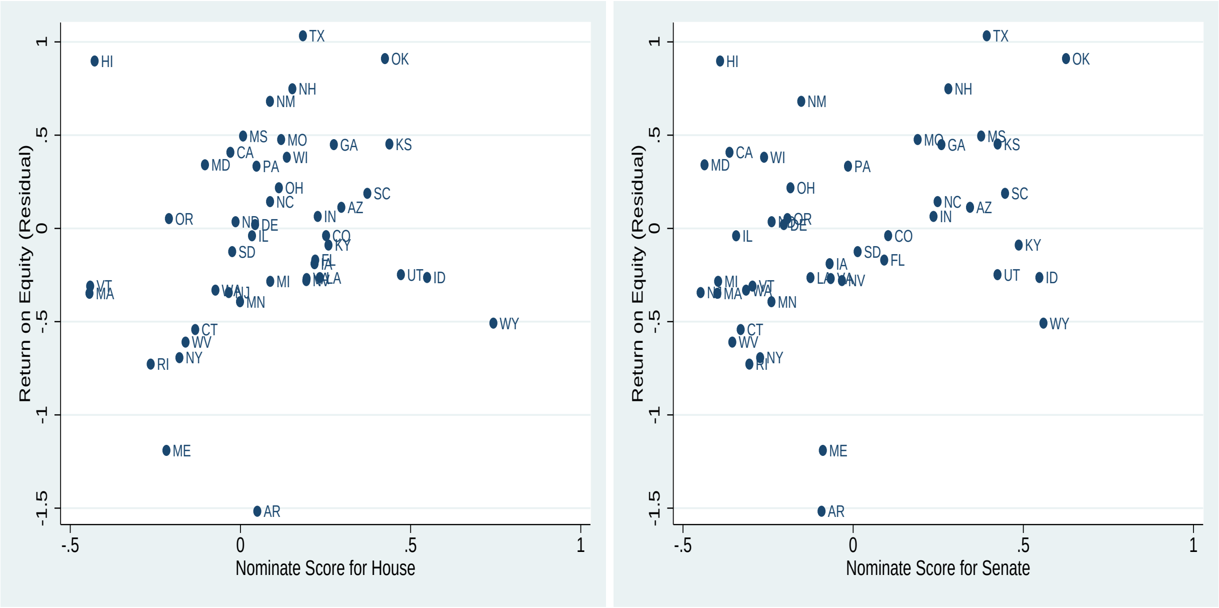

Figure 1: Relationship between Return on Equity and Political Ideology

U.S. House and Senate. For return on equity, we use the residual from filtering out the influence of financial characteristics (equity ratio and bond rating) of utilities, the demographic characteristics (income level and population density) of their service area, and year fixed effects. Observations are collapsed by state.[20] Both panels of the figure show that regulators in states with conservative ideology tend to adjudicate high return on equity.

In Table 2 , we also present regressions of return on equity on Nominate score and other features of political environments[21]:

$$\begin{aligned} Return\ on\ Equity_{it} &= \beta_1 NominateScore_{it} + \beta_2 UnlimitedCampaign_i + \beta_3 Ballot_i \\ &\quad + \beta_4 ElectedRegulators_i + \beta_5 x_{it} + \gamma_t + \varepsilon_{it} \qquad (1) \end{aligned}$$

where *UnlimitedCampaign*, *Ballot*, and *ElectedRegulators* are dummy variables, x_{it} is a vector of demographic and financial covariates for utility i in year t, and γ_t are year fixed effects.[22]

Panel A uses Nominate score for the U.S. House (Columns (1)-(4)) and Senate (Columns (5)-(8)) for the measure of political ideology. In Columns (1) and (5) of Panel A, we use all state-utility-year observations, without conditioning on whether it was a year in which rate case occurred

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by characteristics of the energy industry in the state.

[20] That is, we regress return on equity in each rate case on equity ratio, bond rating of the utilities, income level and population density of their service area, and year fixed effects. Then, we collapse observations by state, and draw scatter plots of residuals and Nominate scores.

[21] In Section 1 of the supplementary material, we also document a sensitivity analysis of these regressions with respect to variation in market structure (deregulation of wholesale and retail markets).

[22] Equation (1) above is the specification of Columns (4) and (8). Whether each variable is included or not varies across specifications.

Table 2: Regression of Return on Equity on Political Ideology

Dependent Variable: Return on Equity

	Panel A: Nominate Score as a Measure of Ideology							
	House of Representatives				Senate			
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Nominate Score	0.924**	0.659**	0.755**	0.706**	0.777**	0.548**	0.555**	0.497**
	(0.370)	(0.313)	(0.345)	(0.325)	(0.291)	(0.250)	(0.242)	(0.246)
Campaign Unlimited			0.292	0.304			0.272	0.283
			(0.257)	(0.243)			(0.231)	(0.219)
Ballot			-0.249	-0.244			-0.251	-0.245
			(0.204)	(0.205)			(0.192)	(0.194)
Elected Regulators				0.357*				0.310*
				(0.190)				(0.180)
Observations	3,329	721	528	528	3,329	721	528	528
R-squared	0.276	0.398	0.391	0.399	0.283	0.403	0.393	0.399
Sample	All	Rate Case	Rate Case	Rate Case	All	Rate Case	Rate Case	Rate Case
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demographic Controls	No	No	Yes	Yes	No	No	Yes	Yes
Financial Controls	No	No	Yes	Yes	No	No	Yes	Yes

	Panel B: Republican Influence as a Measure of Ideology							
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Republican Influence	0.0500	0.227*	0.471***	0.719***	-0.0484	0.824***	1.212***	1.307***
	(0.141)	(0.126)	(0.141)	(0.201)	(0.321)	(0.231)	(0.224)	(0.270)
Observations	3,342	2,481	1,771	1,047	3,342	2,481	1,771	1,047
R-squared	0.703	0.727	0.738	0.771	0.460	0.590	0.629	0.724
Time Period	All	Year>1995	Year>2000	Year>2005	All	Year>1995	Year>2000	Year>2005
Utility-State FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	No	No	No	No

Note: Unit of observation is rate case in Panel A, Columns (2)-(4) and (6)-(8). It is utility-state-year in others. Robust standard errors, clustered by state, are in parentheses. *** $p<0.01$; ** $p<0.05$; * $p<0.1$

(henceforth “rate case year”). In Columns (2)-(4) and (6)-(8), we use only rate case years. The statistical significance of the relationship between return on equity and political ideology is robust to variation in the set of control variables. The magnitude of the coefficient is also fairly large. For example, if we compare Massachusetts, one of the most liberal states, with Oklahoma, one of the most conservative states, the difference in return on equity due to ideology is about 0.61 percentage points[23], which is approximately 47% of the standard deviation in return on equity.[24]

Panel B uses *Republican Influence*, defined as the proportion of Republicans on the public utility commission, as the measure of political ideology. Columns (1) and (4) use the whole set of utility-state-year observations. In other columns, we impose restrictions on data period. The result shows an interesting cross-time pattern in the relationship between *Republican Influence* and return on equity. In Columns (1) and (5), we do not find any significant relationship. However, as we restrict data to later periods, the coefficient of *Republican Influence* not only becomes statistically significant, but its magnitude also becomes large. For example, Column (8) implies that replacing all-Democrat commission with all-Republican commission increases return on equity by 1.3 percentage points in recent years (year>2005), which is approximately one standard deviation. Even after including year fixed effects, the magnitude is .7 percentage points (Column (4)).[25] This finding that *Republican Influence* increases over time is consistent with ideological polarization in the U.S. politics, well documented in McCarty, Poole, and Rosenthal (2008). Using Nominate scores, they document that the ideological distance between the two parties has widened substantially over time.[26] Consistency between cross-time patterns of *Republican Influence* on return on equity and subtle phenomena such as polarization adds a convincing piece of evidence on our argument that political ideology influences adjudication of rate cases.

We find that the influence of (no) restriction on campaign donation from corporations or the availability of ballot propositions is not statistically significant. Considering that the skeptical view toward industry regulation by government in the public choice tradition has been primarily focused the possibility of “capture”, the absence of evidence on a relationship between return on

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[23] If we collapse the data by state, Massachusetts has Nominate score for House around -.45, while Oklahoma has .42. Using the result in Column (4) in the upper panel, we get $0.706 * (.42 - (-.45)) \approx 0.61$.

[24] Once we filter out the influence of financial and demographic characteristics and year fixed effects, 0.61 percentage points in this example is an even larger portion of variation. The residual in return on equity after filtering out these control variables has standard deviation 1.01. Therefore, the difference in return on equity between Massachusetts and Oklahoma predicted solely by ideology based on our regression result is about .6 standard deviation of the residual variation.

[25] In this context, not filtering out year fixed effects is more likely to capture the effect of political ideology more accurately. There can be nationwide political fluctuation that affects political composition of public service commissions. For example, if the U.S. president becomes very unpopular, all candidates from his party may have a serious disadvantage in elections. Thus, political composition of elected public service commission would be affected nationwide. Party dominance for governorship can be affected likewise, which affects composition of appointed public service commission. Including year fixed effects in the regression filters out this nationwide changes in the political composition of regulators, which narrows sources of identification.

[26] For details, see http://voteview.com/polarized_america.htm.

equity and political institutions that can directly affect the extent of capture is intriguing.

Our estimate implies that states with elected regulators are associated with higher level of profit adjudicated for utilities, which contrasts with implications of several existing studies that use outcome variables different from rate of return. Formby, Mishra, and Thistle (1995) argue that election of regulators is associated with lower bond ratings of electric utilities. Besley and Coate (2003) also argue that election of regulators helps to reflect voter preferences better than appointment, thus the residential electricity price is lower when regulators are elected.[27]

2.3.2 Return on Equity and Investment

To understand how political environments of rate regulation affect social welfare, we need to consider their effect on investment, which subsequently affects the reliability of electric power distribution. Thus, we now turn to the relationship between return on equity and investment.

We use two different measures of investment: the average yearly rate of addition to the value of distribution plant, gross of retiring plants (the first measure) and net of retiring plants (the second measure). We take the average rate of addition to the distribution plant per year between rate case years as a proportion of the distribution plant in the preceding rate case year. We run regressions of the following form:

$$Investment_{it} = \alpha_i + \beta_1 Return\ on\ Equity_{it} + \beta_2 x_{it} + \varepsilon_{it}$$

where $Investment_{it}$ is the average yearly investment by utility i after rate case year t until the next rate case, α_i is utility-state fixed effects, $Return\ on\ Equity_{it}$ is the return on equity, and x_{it} is a set of demographic control variables.

The result in Table 3 shows that there is a non-trivial, statistically significant relationship between return on equity adjudicated in a rate case and subsequent investment by utilities. For example, Column (4) in Panel B shows that one percentage point increase in return on equity is associated with .36 percentage point increase in the value of distribution plant, which is approximately a fifth of a standard deviation of net average yearly investment.[28] The economic model

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[27] Besley and Coate (2003) document that electing regulators is associated with electing a Democratic governor (Table 1 on page 1193). They do not include having a Democratic governor as an explanatory variable in the regression of electricity price. Thus, the combination of the relationship between electing regulators and state-level political ideology and our result that liberal political ideology yields low return on equity may explain the contrast between their results and ours. Overall, our study differs from existing studies in many dimensions including data period, key variables, and econometric specifications. A thorough analysis of the complex relationship between various key variables used in existing studies and structural changes in the industry over time would be necessary to uncover the precise source of the differences in results.

[28] Moreover, we can regard this relationship as a *lower bound* of the influence of rate of return on investment. Precisely, investment behavior is influenced by utility's *expectation of future rate of return* rather than one from the preceding rate case. Thus, the rate in the preceding rate case can be regarded as a proxy measure of the future rate of return with a measurement error, i.e., a case of a right-hand-side variable with a measurement error.

Table 3: Regression of Investment on Return on Equity

Panel A: Average Yearly Rate of Addition to Distribution Plant				
Variable	(1)	(2)	(3)	(4)
Return on Equity	0.0023***	0.0024***	0.0031***	0.0031***
	(0.0007)	(0.0007)	(0.0010)	(0.0010)
Observations	510	509	510	509
R-squared	0.030	0.033	0.440	0.439
Utility-State FE	No	No	Yes	Yes
Demographic Controls	No	Yes	No	Yes

Panel B: Average Yearly Rate of Net Addition to Distribution Plant				
Variable	(1)	(2)	(3)	(4)
Return on Equity	0.0022**	0.0022***	0.0036***	0.0036***
	(0.0009)	(0.0009)	(0.0011)	(0.0011)
Observations	510	509	510	509
R-squared	0.017	0.031	0.384	0.384
Utility-State FE	No	No	Yes	Yes
Demographic Controls	No	Yes	No	Yes

Note: Unit of observation is rate case. Robust standard errors, clustered by utility-state, in parentheses. *** p<0.01; ** p<0.05; * p<0.1

in Section 3 of a utility's dynamic investment problem generates a positive correlation between investment and rates of return when regulator types are serially correlated.

2.3.3 Investment and Reliability

A utility's reliability is partially determined by the amount of distribution capital and labor maintaining the distribution system. Our focus is on capital investment. Outages at the distribution level result from weather and natural disaster related damage[29], animal damage[30], tree and plant growth, equipment failure due to aging or overload, and vehicle and dig-in accidents (Brown (2009)). Capital investments that a utility can take to increase its distribution reliability are putting power lines underground, line relocation to avoid tree cover, installing circuit breaks such as re-closers, replacing wooden poles with concrete and steel, installing automated fault location devices, increasing the number of trucks available for vegetation management[31] and incident responses, and replacing aging equipment.

In Table 4, we examine how changes in capital levels affect realizations of reliability, by esti-

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[29] Lightning, extreme winds, snow and ice, and tornadoes are the primary culprits of weather related damage.

[30] Squirrels, racoons, gophers, birds, snakes, fire ants, and large mammals are the animals associated with outages.

[31] Vegetation management involves sending workers to remove branches of trees which have grown close to power lines so that they don't break and damage the power line.

mating regressions of the form:

$$\log(SAIDI_{it}) \quad = \quad \alpha_i + \gamma_t + \beta_1 k_{it} + \beta_2 l_{it} + \beta_3 x_{it} + \varepsilon_{it}$$

where $SAIDI_{it}$ measures outages for utility i in year t, k_{it} is a measure of the utility i's distribution capital stock in year t, l_{it} is utility i's expenditures on operations and maintenance in year t, and x_{it} is a vector of storm and terrain related explanatory variables. In this regression, there is mis-measurement on the left hand side, mis-measurement on the right hand side, and a likely correlation between ε shocks and expenditures on capital and operations and maintenance. Mis-measurement on the left hand side is because measurement systems for outages are imperfect. Mis-measurement on the right hand side arises by aggregating different types of capital into a single number based on an estimated dollar value. The error term is likely to create a bias in our estimate of the effect of adding capital to reduce outages. We employ utility-state fixed effects, so that the variation identifying the coefficient on capital is within utility-state over time.[32] Even including utility-state fixed effects, a prolonged period of stormy weather would damage capital equipment and increase outage measures. The utility would compensate by replacing the capital equipment. Thus we would see poor reliability and high expenditure on capital in the data. This correlation would cause an upward bias in our coefficient estimates on β_1 and β_2, which reduces estimated sensitivity of SAIDI to investment.[33] Despite this potential bias, the result in Column (4), which is our preferred specification, shows a strong negative relationship between capital investment and SAIDI.

2.3.4 Political Ideology and Utility Management (Energy Loss)

The preceding three subsections indicate one important channel through which political environments influence social welfare: improvement of reliability under conservative commissioners because higher returns lead to higher investment.[34] On the other hand, conservatives' favoritism toward the utility relative to consumers implies a possibility that more conservative commissioners may aggravate potential moral hazard by monopolists. To take a balanced view on this issue, we investigate the relationship between the political ideology of regulators and *efficiency of utility management*. Our measure of static efficiency is how much electricity is lost during transmission and distribution: *energy loss*. The amount of energy loss is determined by system characteristics and actions taken by the utility's managers to optimize system performance.

We find that conservative environments are associated with more energy loss. Table 5 presents

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[32] Absent utility-state fixed effects, utilities in territories prone to outages would invest in more capital to prevent outages. This would induce a correlation between high capital levels and poor reliability.

[33] Recall that standard reliability measures of outage frequency and duration are such that lower values indicate more reliable systems.

[34] In Section 4 of the supplementary material, we present an analysis of the direct (reduced-form) relationship between the political ideology of regulators and reliability.

Table 4: Regression of Reliability Measure on Investment

	Dependent Variable: SAIDI		Dependent Variable: log(SAIDI)	
Variable	(1)	(2)	(3)	(4)
Net Distribution Plant	-9.92*	-11.67*		
($ million)	(5.28)	(5.94)		
log(Net Distribution Plant)			-0.272	-0.524***
($ million)			(0.170)	(0.173)
Observations	1,687	1,195	1,684	1,192
R-squared	0.399	0.663	0.744	0.769
Utility-State FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Controls	O&M expense	O&M expense Weather	O&M expenses	O&M expenses Weather

Note 1: Robust standard errors, clustered by state, in parentheses. *** p<0.01; ** p<0.05; * p<0.1
Note 2 A higher value of SAIDI means lower reliability.

regressions of the following form:

$$\log(energy\ loss_{it}) = \alpha_i + \gamma_t + \beta_1 Republican\ Influence_{it} + \beta_2 x_{it} + \varepsilon_{it}$$

where x_{it} is a set of variables that affect energy loss by utility i in year t, such as distribution capital, operation and management expenses, and the magnitude of sales.

The values for energy loss are non-trivial. The average amount of energy loss is 7% of total production. In Panel A, we find that moving from all Republican commissioners to zero Republican commissioners reduces energy loss by 13%, which would imply 1 percentage point less total energy generated for the same amount of energy ultimately consumed.[35] This is large. A back-of-the-envelope calculation for the cost of this 1% more electricity is 3.7 billion dollars per year.

We conclude that conservative political environment potentially encourages better reliability through higher return on equity and more investment, but it also leads to less static productivity as measured by energy loss. To conduct a comprehensive analysis of the relationship between political environment and welfare from utility regulation, we now specify and estimate a model that incorporates both features.

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[35] Panel B, based on Nominate score, yields a larger magnitude of the estimate. Since the analysis using Nominate score is more subject to confounding factors (unobserved heterogeneity across utilities), we focus on the result from Panel A. However, the consistency in the direction of the results between Panels A and B strengthens our interpretation. We also ran these specifications including peak energy demand to account for variance in load. The results are similar but for a slightly lower magnitude of the Nominate score.

Table 5: Regression of Log Energy Loss on Political Ideology

Dependent Variable: log(energy loss)

Panel A: Republican Influence as a Measure of Ideology

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Republican Influence	0.169***	0.118**	0.133**	0.133**	0.130**	0.130**
	(0.0538)	(0.0550)	(0.0580)	(0.0590)	(0.0592)	(0.0592)
log(Net Distribution Plant)			0.483***	0.460**	0.418**	0.418**
			(0.168)	(0.173)	(0.166)	(0.166)
log(Operations and Maintenance)				0.0738	0.0586	0.0586
				(0.0775)	(0.0778)	(0.0778)
log(Sales)					0.221	0.221
					(0.143)	(0.143)
Observations	3,286	3,286	3,276	3,276	3,263	3,263
R-squared	0.906	0.908	0.908	0.908	0.909	0.909
Utility-State FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	Yes	Yes	Yes	Yes
Weather and Demographics	No	No	No	No	No	No
Sample Restrictions	Yes	Yes	Yes	Yes	Yes	No

Panel B: Nominate Score as a Measure of Ideology

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Nominate Score	1.025**	1.025**	0.516*	0.623**	0.609**	0.609**
	(0.448)	(0.448)	(0.277)	(0.258)	(0.255)	(0.255)
log(Net Distribution Plant)			0.974***	0.703***	0.662***	0.662***
			(0.0378)	(0.106)	(0.120)	(0.120)
log(Operations and Maintenance)				0.306**	0.286**	0.286**
				(0.124)	(0.119)	(0.119)
log(Sales)					0.0717	0.0717
					(0.0538)	(0.0538)
Observations	1,765	1,765	1,761	1,761	1,761	1,761
R-squared	0.145	0.145	0.712	0.719	0.720	0.720
Utility-State FE	No	No	No	No	No	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather and Demographics	Yes	Yes	Yes	Yes	Yes	Yes
Sample Restrictions	Yes	Yes	Yes	Yes	Yes	No

Note 1: Unit of observation is utility-state-year. Robust standard errors, clustered by state, in parentheses. *** p<0.01; ** p<0.05; * p<0.1

Note 2: In columns (1)-(5) in each panel, we use the following sample restriction: $0.5 < \text{efficiency} < 1$ where $\text{efficiency} = \frac{\text{total sales}}{\text{total sales}+\text{loss}}$. We use this restriction to minimize the influence of outliers in the energy loss variable.

3 Model

We specify an infinite-horizon dynamic game between a regulator and an electric distribution utility. Each period is one year.[36] The players discount future payoffs with discount factor β.

The state space consists of the value of utility's capital k and the regulator's weight on consumer surplus versus utility profits, α.[37] Each period, the regulator chooses a rate of return on the utility's capital base, r, and leniency of auditing, κ ($\kappa \in [0,1]$), or equivalently, audit intensity $1-\kappa$. After the utility observes the regulator's choices, it decides how much to invest in distribution capital and how much managerial effort to engage in for cost reduction.

Audit intensity is directly linked to materials cost pass-through rate. When regulators are maximally lenient in auditing ($\kappa = 1$), i.e., minimally intense in auditing ($1-\kappa = 0$), they completely reflect changes in material costs of electricity in consumer prices. It is an index of how high-powered the regulator sets the incentives for electricity input cost reduction.

The regulator's weight on consumer surplus evolves exogenously between periods according to a Markov process. The capital base evolves according to the investment level chosen by the utility. We now detail the agents' decision problems in terms of a set of parameters to be estimated and define the equilibrium notion.

3.1 Consumer Demand System

We assume a simple inelastic demand structure. An identical mass of consumers of size N are each willing to consume $\frac{Q}{N}$ units of electricity up to a choke price $\bar{p} + \tilde{\beta} \log \frac{k}{N}$ per unit:

$$D(p) = \begin{cases} Q & \text{if } p \leq \bar{p} + \tilde{\beta} \log \frac{k}{N} \\ 0 & \text{otherwise} \end{cases} .$$

$\tilde{\beta}$ is a parameter that captures a consumer's preference for a utility to have a higher capital base. All else equal, a higher capital base per customer results in a more reliable electric system as demonstrated empirically in Table 4. This demand specification implies that consumers are perfectly inelastic with respect to price up until the choke price. We make this simplifying assumption to economize on computational costs during estimation. Joskow and Tirole (2007) similarly assume inelastic consumers in a recent theoretical study of electricity reliability. Furthermore, estimated elasticities for electricity consumption are generally low, on the order of -0.05 to -0.5 (Bernstein and Griffin (2005), Ito (2013)). Including a downward sloping demand function is conceptually

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[36] In the data, rate case does not take place every year. For the years without a rate case in the data, we assume that the outcome of the hypothetical rate case in the model is the same as the previous rate case in the data.

[37] We will parameterize and estimate α as a function of the political environment.

simple, but slows down estimation considerably.[38]

The per unit price that consumers ultimately face is determined so that the revenue to the utility allows the utility to recoup its materials costs and the adjudicated return on its capital base:

$$p = \frac{rk + p_f Q(1 + \kappa(\bar{e} - e + \varepsilon))}{Q} \tag{2}$$

where p_f is the materials cost which reflects the input cost of electricity,[39] r is the regulated rate of return on the utility's capital base k, and κ is the leniency of auditing, or equivalently, the pass-through fraction, chosen by the regulator, whose problem we describe in Section 3.3. $\bar{e}$ is the amount of energy loss one could expect with zero effort, e is the managerial effort level chosen by the utility, and ε is a random disturbance in the required amount of electricity input. We will elaborate on the determination of these variables as results of the utility and regulator optimization problems below. For now, it suffices to know that this price relationship is an accounting identity. pQ is the revenue requirement for the utility. The regulator and utility only control price indirectly through the choice variables that determine the revenue requirement.

It follows that per-period consumer surplus is:

$$CS = (\bar{p} + \tilde{\beta} \log \frac{k}{N})Q - rk - p_f Q(1 + \kappa(\bar{e} - e + \varepsilon)).$$

The first term is the utility, in dollars, enjoyed by consuming quantity Q of electricity. The second and the third term are the total expenditure by consumers to the utility.

3.2 Utility's Problem

The per-period utility profit, π, is a function of the total quantity, unit price, materials cost, investment expenses, and managerial effort cost:

$$\pi(k', e; k, r, \kappa) = pQ - (k' - (1-\delta)k) - \eta(k' - (1-\delta)k)^2 - p_f Q(1 + \bar{e} - e + \varepsilon) - \gamma_e e^2 + \sigma_i u_i$$

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[38] A downward sloping demand function increases the computations involved in the regulator's optimization problem because the mapping from revenue requirement to consumer price, which is necessary to evaluate the regulator's objective function, requires solving a nonlinear equation rather than a linear equation.

[39] In principle, rate cases are completed and prices (*base rates*) are determined before the effort by the utility and energy loss are realized. However, an increase in the cost of power purchase due to an unanticipated increase in energy loss can typically be added *ex-post* to the price as a *surcharge*. Most states have "automatic adjustment clauses" that allow reflection of the cost increase from the energy loss in the price without conducting formal rate reviews. Moreover, the regulator can ex-post disallow pass-through if it deems the utility's procurement process imprudent. Thus, inclusion of both regulator's audit κ and utility's effort e in determination of p is consistent with the practice. This practice also justifies our assumption of inelastic electricity demand, because consumers are often unaware of the exact price of the electricity at the point of consumption.

where k' is next period's capital base, η is the coefficient on a quadratic adjustment cost in capital to be estimated, δ is the capital depreciation rate, and γ_e is an effort cost parameter to be estimated. u_i is an investment-level-specific i.i.d. error term which follows a standard extreme value distribution multiplied by coefficient σ_i.[40] u_i is known to the utility when it makes its investment choice, but the regulator only knows its distribution. η's presence is purely to improve the model fit on investment. Such a term has been used elsewhere in estimating dynamic models of investment, e.g., in Ryan (2012).

Effort increases the productivity of the firm by reducing the amount of materials needed to deliver a certain amount of output. The notion of the moral hazard problem here is that the utility exerts unobservable effort level e, the regulator observes the total energy loss which is a noisy outcome partially determined by e, and the regulator's "contract" for the utility is linear in this outcome. We assume effort is the only determinant of the materials cost other than the random disturbance, which implies that capital does not affect materials cost. Furthermore, effort does not reduce outages. While this separation is more stark than in reality, it is a reasonable modeling assumption for several reasons. The capital expenditures for reducing line loss – replacing the worst performing transformers – are understood to be small. In contrast, capital expenditures for improving reliability, such as putting lines underground, fortifying lines, adding circuit breakers and upgrading substations, are large. As a result, empirically we can not estimate the beneficial impact of capital expenditures on line loss as we do for reliability, and we do not include this avenue in the theoretical model.[41]

The investment choice, $k' - (1-\delta)k$, could also be written as a function of the regulator's earlier choices r and κ, but this is unnecessary. The optimal choice of k' does not depend on κ or this period's r because neither the cost of investment nor the benefits of the investment depend on those choices. The benefits will depend on the *future stream* of r choices, but not this period's r. Substituting the price accounting identity (equation (2) on page 19) into the utility's per-period payoff function simplifies the payoff function to

$$\pi(k,k',e,Q,p) = rk - (k' - (1-\delta)k) - \eta(k' - (1-\delta)k)^2 + (\kappa - 1)p_f Q(\bar{e} - e + \varepsilon) - \gamma_e e^2 + \sigma_i u_i.$$

The utility's investment level determines its capital state next period. The utility's dynamic problem is to choose effort and investment to maximize its expected discounted value:

$$v_u(k,\alpha) = \max_{k',e} E[\pi(k,k',e,r,\kappa)|u_i] + \beta E[v_u(k',\alpha')|k,k',e,r,\kappa,\alpha].$$

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[40] This error term is necessary to rationalize the dispersion in investment that is not explained by variation across the state space.

[41] A similar argument holds for effort and reliability. In practice, the non-capital expenditures to improve reliability such as vegetation management are small relative to overall operations expenditures such that we can not estimate their effect.

The utility's optimal effort choice has an analytical expression which we use in estimation:

$$e^*(\kappa) = \min\left\{ \frac{-(\kappa-1)p_f Q}{2\gamma_e}, \bar{e} \right\}$$

When κ is equal to one, which implies minimal audit intensity ($1-\kappa=0$), the utility is reimbursed every cent of electricity input expenses. Thus, it will exert zero effort. If κ is equal to zero, then the utility bears the full cost electricity lost in distribution. Effort is a function of the regulator's auditing intensity because the regulator moves first within the period.

3.3 Regulator's Problem

The regulator's payoff is the geometric mean[42] of expected discounted consumer welfare, or consumer value (CV)[43], and the utility value function, v_u, minus the cost of auditing and the cost of deviating from the market return:

$$u_R(r,\kappa;\alpha,k) = E[CV(r,\kappa,k,e)|r,\kappa]^{\alpha} E[v_u(r,\kappa,k,e)|r,\kappa]^{1-\alpha} - \gamma_\kappa(1-\kappa)^2 - \gamma_r(r-r^m)^2$$

where α is the weight the regulator puts on consumer welfare against utility value, r is the regulated rate of return, $1-\kappa$ is the auditing intensity, γ_κ is an auditing cost parameter to be estimated, r^m is a benchmark market return for utilities, and γ_r is an adjustment cost parameter to be estimated. CV is the value function for consumer surplus:

$$E[CV(r,\kappa,k,e)|r,\kappa] = \sum_{\tau=t}^{\infty} \beta^{\tau-t} E[(\bar{p} + \tilde{\beta}\log\frac{k_\tau}{N})Q - r_\tau k_\tau - p_f Q(1+\kappa_\tau(\bar{e_\tau} - e_\tau + \varepsilon_\tau))|r_t,\kappa_t]].$$

By default the utility is reimbursed for its total electricity input cost. The regulator incurs a cost for deviating from the default of full pass-through: $\gamma_\kappa(1-\kappa)^2$. The regulator must investigate, solicit testimony, and fend off legal challenges by the utility for disallowing the utility's electricity costs. The further the regulator moves away from full pass-through, the more cost it incurs. This is a classical moral hazard setup. Line loss is a noisy outcome resulting from the utility's effort choice. The regulator uses a linear contract in the observable outcome, as in Holmstrom and Milgrom (1987), to incentivize effort by the utility.

The term $\gamma_r(r-r^m)^2$ is an adjustment cost for deviating from a benchmark rate of return such as the average return for utilities across the country. A regulator who places all weight on utility

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[42] An important principle in rate regulation is to render a non-negative economic profit to utilities, which is a type of "individual rationality condition". The usage of geometric mean in this specification renders tractability of the model in dealing with such condition, by ensuring non-negative value of the firm in the solution. This specification is also analogous to the Nash bargaining model in which players maximize the geometric mean of their utilities.

[43] Consumer value is employed in dynamic models of merger regulation such as Mermelstein et al. (2012).

profits would not be able in reality to adjudicate the implied rate of return to the utility. Consumer groups and lawmakers would object to the supra-normal profits enjoyed by investors in the utility relative to similar investments. A regulator who places more weight on utility profits can increase rates by small amounts[44], but only up to a certain degree.

The two terms, $\gamma_\kappa(1-\kappa)^2$ and $\gamma_r(r-r^m)^2$, in the regulator's per-period payoff are both disutility incurred by the regulator for deviating from a default action. Regulators with different weights on utility profits and consumer surplus will deviate from these defaults to differing degrees.

We assume that the weight on consumer surplus is a function of political composition of the commission and the political climate. Specifically,

$$\alpha = a_0 + a_1 rep + a_2 d$$

where *rep* is the fraction of Republican commissioners in the state, d is the Nominate score of the utility's state, and the vector $\mathbf{a} \equiv (a_0, a_1, a_2)$ is a set of parameters to be estimated.

3.4 Equilibrium

We use the solution concept of Markov Perfect Equilibrium.

Definition. *A Markov Perfect Equilibrium consists of*

- *Policy functions for the utility:* $k'(k,\alpha,r,\kappa,u_i)$ *and* $e(k,\alpha,r,\kappa,u_i)$
- *Policy functions for the regulator:* $r(k,\alpha)$ *and* $\kappa(k,\alpha)$
- *Value function for the utility:* $v_u(k,\alpha)$
- *Value function for consumer surplus ("consumer value"):* $CV(k,\alpha)$

such that

1. *The utility's policy function is optimal given its value function and the regulator's policy functions.*
2. *The regulator's policy function is optimal given consumer value, the utility's value function, and the utility's policy functions.*
3. *The utility's value function and consumer value function are equal to the expected discounted values of the stream of per-period payoffs implied by the policy functions.*

3.5 Discussion of Game

There are two, somewhat separate, interactions between the regulator and the utility. The first involves the investment choice by the utility and the rate of return choice by the regulator. The second involves the effort choice by the utility and the audit intensity choice by the regulator.

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[44] For example, the regulator can accept arguments that the utility in question is more risky than others.

In the first, the regulator and utility are jointly determining the amount of investment in the distribution system. The regulator's instrument in this dimension is the regulated rate of return. In the second, the utility can engage in unobservable effort which affects the cost of service by decreasing the amount of electricity input need to deliver a certain amount of output. The regulator's instrument in this dimension is the cost pass-through, or auditing policy.

3.5.1 Investment, Commitment, and Averch-Johnson Effect

If the utility expects a stream of high rates of return, it will invest more. The regulator can not commit to a path of returns, however. Therefore, the incentives for investment arise indirectly through the utility's *expectation* of the regulated rates that the regulator adjudicates from period to period. This dynamic stands in contrast to the Averch-Johnson effect (Averch and Johnson (1962)) whereby rate-of-return regulation leads to over-investment in capital or a distortion in the capital-labor ratio towards capital. The idea of Averch-Johnson is straightforward. If a utility can borrow at rate s, and earns a regulated rate of return at $r > s$, then the utility will increase capital. The key distinction in our model is that r is *endogenously chosen* by the regulator *as a function of the capital base* to maximize the regulator's objective function. r may exceed s at some states of the world, but if the utility invests too much, then r will be endogenously chosen below s. This feature of the model might seem at odds with the regulatory requirement that a utility be allowed to earn a fair return on its capital. However, capital expenditures must be incurred prudently, and the resulting capital should generally be "used and useful." In our formulation, the discretion to decrease the rate of return substitutes for the possibility of capital disallowances when regulators have discretion over what is deemed "used and useful."

3.5.2 Cost Pass-Through and Auditing

The costs of unobservable effort of finding qualified dispatchers and engineers, procuring electricity cost-effectively from nearby sources, and tracking down problems in the distribution network that are leading to loss are borne by the utility's management. If the regulator accepts the costs associated with energy loss without question, then the utility's management has no incentive to exert unobservable effort. Thus, there is a moral hazard problem in the game between the regulator and the utility. The regulator chooses how high powered to set the incentives for the utility to exert unobservable effort through the fraction of electricity input costs it allows the utility to recoup.[45]

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[45] This friction in regulation is mentioned in regulatory proceedings and regulatory documents. For example, Hempling and Boonin (2008) states that "[cost pass-through mechanisms]... can produce disincentives for utility operational efficiency, since the clause allows the utility to recover cost increases, whether those cost increases arise from... (c) line losses." This document goes on to assert that an effective pass-through mechanism should contain meaningful possibilities for auditing the utility's operational efficiency to mitigate such concerns.

The regulator's actions in both interactions are determined by its weight on consumer surplus. Intuitively, the utility likes high returns and weak auditing. Therefore, the more weight the regulator places on utility profits, the higher the rate of return it will regulate, and the less auditing it will engage in. We now turn to estimating the parameters of this game with a focus on the mapping between political environment variables to the regulator's weight on consumer surplus.

4 Estimation

We estimate eight parameters: the effort cost parameter γ_e, the audit cost parameter γ_κ, the quadratic adjustment cost coefficient η, the market rate adjustment cost γ_r, the coefficient of the error term in the utility's investment decision σ_i, and the mapping from political climate of the state and party affiliation of regulators to weight on consumer surplus versus utility profits, $\mathbf{a} \equiv (a_0, a_1, a_2)$. We denote $\theta \equiv (\gamma_e, \eta, \gamma_\kappa, \gamma_r, \sigma_i, \mathbf{a})$. We fix the yearly discount factor of the players, β, at 0.96. We fix the capital depreciation rate at 0.041.[46] We set p_f, the wholesale price of electricity, to \$70 per megawatt-hour. We set $\bar{e}$ so that zero effort results in the utility losing one-third of its electricity input cost in distribution.

We use a sub-sample of the data for estimation. We excluded utilities with less than 50,000 customers or whose net distribution capital per customers exceeds \$3,000. These outlier utilities are mostly in the Mountain West and Alaska. The population density and terrain of these utilities are sufficiently different from the bulk of U.S. electric distribution utilities that we do not want to combine them in the analysis. We also excluded utility-years where the energy loss exceeds 15% or the absolute value of the investment rate exceeds 0.1. The energy loss criterion eliminates around twenty observations.[47] The investment restriction is to deal with acquisitions and deregulation events. Our final sample is 2331 utility-state-year observations, just above two-thirds of the full sample of utility-state-years with the bulk of the difference being from dropping small utilities.

4.1 Demand Parameters: Value of Reliability

We calibrate the demand parameters so that the willingness-to-pay of the representative consumer for a year of electricity service at the average capital level in the data is \$24,000.[48] We set the willingness-to-pay for improving reliability, as measured by SAIDI, by one minute to \$2.488 per

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[46] This is the average level in our data computed from FERC Form 1 Depreciation Expense and the IRS MACRS depreciation rate for electric distribution capital.

[47] The implied energy loss values are unreliable in these cases because they are derived from utility territories which operate in multiple states, but report one aggregate level of energy loss.

[48] The \$24,000 number is somewhat arbitrary as we are not modeling whether the consumer is residential, commercial, or industrial, nor can one reliably elicit this number. Adjusting this value will have a direct effect on the estimated level of a_0, but is unlikely to affect other results in this paper.

customer per year. The choice of the value of reliability has first order implications for the counterfactual analysis that we perform. We estimated this number using the results of LaCommare and Eto (2006) who use survey data to estimate the cost of power interruptions. Estimated values for improvements in reliability are heterogenous by customer class, ranging from \$0.5-\$3 to avoid a 30 minute outage for residential consumers to \$324-\$435 for small commercial and industrial consumers to \$4,330-\$9,220 for medium to large commercial and industrial consumers.[49] To get to \$2.488 per minute of SAIDI per customer per year, we use the mid-point of the estimates by customer class, and set 0.38 percent of consumers to medium to large commercial and industrial, 12.5 percent to small commercial and industrial, and the remaining 87.12 percent to residential.[50]

From these values, a crude calculation for the level of under-investment is derived as follows. The net present value of \$2.488 per minute per customer per year is \$62.224 per minute per customer at a discount factor of 0.96. The reliability on capital regression implies that the one-time, per-customer change in the capital base required to improve SAIDI by one minute is \$34.432 for the mean utility. The benefit exceeds the cost such that moderate decreases in the benefit would still be consistent with under-investment. Our model improves the credibility of this crude calculation by including depreciation, future investment, and investment costs not captured by the book value of the assets.[51]

4.2 Regulator and Utility Parameters

We estimate the parameters in θ using a two-step procedure for dynamic games following Bajari et al. (2007) (BBL) and Pakes et al. (2007). This method avoids computationally costly re-solving of the equilibrium. The estimation objective evaluates candidate sets of parameters by simulating value functions implied by those parameters and the observed policies in the data, and comparing the observed policies to those which are optimal given the simulated value functions and candidate parameters. Our problem has two features which are non-standard. First, the effort and regulatory auditing policies are unobserved.[52] Second, one of the state variables, the regulator's weight on consumer surplus is not observed directly. The solution in both cases is to derive the unobserved quantity as a function of model parameters and data.

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[49] While some of these customers may have back-up generation, that is rarely enough to support full operation of the plant during the outage. For example, a hospital might back-up enough power to keep treating its current patients, but divert new emergency room patients to another hospital, or cancel non-urgent outpatient procedures.

[50] The survey measures for willingness-to-pay to improve reliability are fraught with issues such as truthful elicitation and aggregating surveys with differently phrased questions. Accordingly, we later assess robustness of our results to these values.

[51] We assume no heterogeneity in these values and costs. If the value of reliability is positively correlated with the cost of improving reliability, then this calculation is no longer valid. Our data on reliability were not rich enough to measure heterogenous costs of improving reliability.

[52] Unobserved effort is a challenge in the empirical analysis of moral hazard problems (Misra and Nair (2011), Lewis and Bajari (2013)).

The data are, for every utility-state (i) and year (t): a capital base k_{it}, an investment level inv_{it}, realized energy loss l_{it} in MWh, a return on capital r_{it}, a market size Q_{it} in MWh, a fraction of Republican utility commissioners rep_{it}, and a state Nominate score d_{it}. The following list describes the steps for calculating the estimation objective function for a given set of model parameters θ. We then detail each step:

Estimation Steps

1. Consider candidate model parameters $\theta = (\gamma_e, \eta, \gamma_\kappa, \gamma_r, \sigma_i, \mathbf{a})$.
2. Transform political data into weights on consumer surplus using **a**. Estimate a Markov process for weight on consumer surplus.
3. Transform energy loss into unbiased estimates of effort and audit intensity using γ_e and first order condition for optimal effort.
4. Estimate policy functions for investment, effort, rate of return, and audit intensity.
5. Simulate value functions implied by θ and estimated policy functions.
6. Solve for optimal policies given by implied value functions and θ.
7. Compute moments implied by optimal policies and Markov process for weight on consumer surplus.
8. Calculate objective function.

We discretize the state space into a grid of points for capital level and weight on consumer surplus level. We first transform the data on the fraction of Republican commissioners and the Nominate score of a state into an implied weight on consumer surplus by $\alpha_{it} = a_0 + a_1 rep_{it} + a_2 d_{it}$. This resolves the issue of one dimension of the state space being unobserved. We use the implied α_{it} series to approximate a first-order Markov process for the weight on consumer surplus over the discretized grid.

Next, we invert energy loss l_{it} into an unbiased estimate of effort according to the model. First, l_{it} is equal to electricity procured minus electricity delivered:

$$l_{it} = Q_{it}(1 + \bar{e} - e_{it} + \varepsilon_{it}) - Q_{it}.$$

We assume that ε_{it} has mean zero. It follows that

$$\hat{e}_{it} = \bar{e} - \frac{l_{it}}{Q_{it}}.$$

$\hat{e}_{it}$ is regressed on functions of state variables to produce an estimated effort policy function. The estimation error due to $\hat{e}_{it}$ being different from e_{it} does not change the asymptotic properties of this step.[53] We assume the utility serves Q units of energy every period, where Q is the mean of Q_{it}

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[53] The residual from this policy function estimation does affect the value function estimates in theory, but in practice

across all utilities and years.[54]

We then recover an estimate of the auditing intensity. The first order condition of the utility with respect to effort choice implies $\kappa = 1 - \frac{2\gamma_e e}{Q p_f}$. This relationship generates the audit policy κ_{it} from the estimated effort levels and the candidate effort cost parameter γ_e. Since this function is linear in effort, the unbiased estimate of effort generates an unbiased estimate of audit intensity. This resolves the two non-standard issues in the two-step estimation procedure.

We next regress the policy variables $inv_{it}, \hat{e}_{it}, r_{it}$, and $\hat{\kappa}_{it}$ on the state variables k_{it} and α_{it}. Starting from each point on the discretized state space grid and using the candidate parameters and estimated policies, we forward-simulate 300 paths of length 200 of α and k.[55] For each path, we compute the stream of per-period payoffs for both the utility and consumers. The mean net present value across paths at each point in the state space constitutes the estimated value functions for the utility and consumers.

Given the candidate model parameters and the simulated value functions, we solve for the optimal policies for each player in each state given the opponent's observed policies. The criterion function compares these optimal policies to the initial estimated policy functions. Intuitively, the procedure is choosing the model's parameters such that the observed policies are equilibrium policies. We construct an extremum criterion function composed of the difference between observed policies and predicted policies at different points in the state space. We add eight more moments into the criterion function: the mean and the variance of three variables, the rate of return, investment level, and energy loss, mean audit intensity,[56] and the regression coefficients of effort and rate of return on fraction of Republican commissioners and Nominate scores. Explicitly, the criterion function has the following components:

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the number of stochastic shocks we could accommodate computationally is limited.

[54] Similar to the energy loss shocks, allowing a stochastically evolving Q is conceptually simple, but computationally difficult because of the forward simulation step which we describe shortly.

[55] This step is where allowing for more stochastic processes such as stochastically evolving Q is computationally difficult because of speed and memory requirements for the additional simulations that would be necessary.

[56] Mean audit intensity is not directly observable like the other statistics. As audit intensity corresponds to pass-through of lost energy in our model, we estimated a regression of revenue on energy loss. However, the implied pass-through rate was above 1, though statistically we could not rule out values between 0.91 and 1. We set the mean audit intensity to 0.975 for the purpose of estimation. This reflects that challenges to automatic pass-through are extremely rare. Altering this value between 0.9 up to just below 1 does not change the ultimate counterfactual results qualitatively. However, such a change may affect the estimated audit cost and effort cost parameters.

$$G(\theta) = \begin{bmatrix} \frac{1}{N_{k,\alpha}} \sum_{k,\alpha} inv(k,\alpha) - \hat{inv}(k,\alpha;\theta) \\ \frac{1}{N_{k,\alpha}} \sum_{k,\alpha} e(k,\alpha) - \hat{e}(k,\alpha;\theta) \\ \frac{1}{N_{k,\alpha}} \sum_{k,\alpha} r(k,\alpha) - \hat{r}(k,\alpha;\theta) \\ \frac{1}{N_{k,\alpha}} \sum_{k,\alpha} \kappa(k,\alpha) - \hat{\kappa}(k,\alpha;\theta) \\ \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} r_{it} - \hat{\bar{r}}(\theta) \\ \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} (r_{it} - \bar{r})^2 - \hat{\sigma}_r^2(\theta) \\ \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} inv_{it} - \hat{\bar{inv}}(\theta) \\ \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} (inv_{it} - \bar{inv})^2 - \hat{\sigma}_{inv}^2(\theta) \\ \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} e_{it} - \hat{\bar{e}}(\theta) \\ \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} (e_{it} - \bar{e})^2 - \hat{\sigma}_e^2(\theta) \\ \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} \kappa_{it} - \hat{\bar{\kappa}}(\theta) \\ \hat{\beta}_{e,data} - \hat{\beta}_e(\theta) \\ \hat{\beta}_{r,data} - \hat{\beta}_r(\theta) \end{bmatrix}$$

where $\hat{x}$ for policy x denotes the optimal choice implied by the model at the candidate parameters θ. We minimize the weighted sum of squares of $G(\theta)$:

$$\hat{\theta} = \underset{\theta}{\operatorname{argmin}}\, G(\theta)' W G(\theta)$$

where W is a weighting matrix. The first four components of $G(\theta)$ are the differences between observed policies and implied optimal policies averaged across points in the state space. The next seven components are the mean and the variance of outcomes.[57] The final two components compare regression coefficients from the data to regression coefficients implied by the model. We match two regressions: regulated rate of return on Nominate score and fraction of republican commissioners, and effort on Nominate score and fraction of republican commissioners. We set the weighting matrix W to adjust for differences in scaling across moments. We compute confidence intervals by block-bootstrap, clustering by utility-state.

5 Estimation Results

In this section, we interpret the economic magnitude of parameter estimates and discuss the empirical identification of the parameters. Table 6 shows the estimation results.

Magnitudes and Model Fit: The effort cost parameter, γ_e, implies that decreasing energy loss by 1% at the mean effort would entail a disutility worth about \$284,000 to utility management. This is comparable to the cost of hiring one to two power system engineers. The adjustment cost for

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[57] As the parameter vector **a** affects transitions across states, these moments are not implied by matching observed policies to implied optimal policies state by state.

Table 6: Parameter Estimates

Parameter	Related Model Component	Estimate	95%-CI Lower-bound	95%-CI Upper-bound
$\gamma_e(10^7)$	effort cost	5.8504	5.2900	6.6613
$\gamma_\kappa(10^{10})$	audit cost	17.4760	13.4229	21.0956
$\gamma_r(10^{10})$	market return adjustment cost	2.8868	2.0778	9.1118
$\eta(10^4)$	quadratic investment cost	11.2177	5.9422	22.3227
$\sigma_i(10^7)$	investment-level-specific error	2.4146	1.0069	8.6828
a_0	weight on consumer surplus	0.9998	0.9971	1.0052
a_1	weight on consumer surplus	-0.0046	-0.0211	-.0005
a_2	weight on consumer surplus	-0.0019	-.0020	0.0012
N		2331		
Criterion		0.0006335		

capital, η, is small relative to the actual cost of capital, that is, the linear term in investment. For a 10% investment from the mean capital level, the adjustment cost is equal to 14.87% of the cost of the capital itself. This parameter is likely picking up heterogeneity across utilities not specified in the dynamic model, such as population growth rates and idiosyncratic features of the terrain. The regulator's cost parameters, γ_r and γ_κ, imply that adjusting the rate of return by one standard deviation in the data (1.3 percentage points) from the mean bears the same cost as decreasing cost pass-through rate by 0.1 percentage points from the mean (97.5% to 97.4%).

The mapping from political variables to weight on consumer surplus describes regulator heterogeneity. a_0 sets the level of weight on consumer surplus. It is very close to one. This reflects that current electricity prices are a very small fraction of willingness-to-pay for electricity. The value is sensitive to the calibration of willingness-to-pay for electricity, described on page 24. a_1 is larger in magnitude than a_2. Both are negative implying that more conservative areas, whether measured by Nominate scores or fraction of republican commissioners, place relatively less weight on consumer surplus than liberal areas, leading to higher rates of return and more energy loss.

In Figure 2, we plot the policy surfaces at the estimated parameters for investment and rate of return as functions of capital per capita and the weight on consumer surplus. Both the rate of return and investment are decreasing in the two dimensions. Investment decreases in the weight on consumer surplus because of persistence in the stochastic process of the weight. In Figure 3, we plot all of the policy functions at the estimated parameters, averaged across levels of capital, in the dimension of weight on consumer surplus. Auditing is increasing in the weight on consumer surplus, which implies that effort is also increasing in this dimension.

In terms of model fit, the estimated model does well matching the first moments of the key choice variables. While the model predicts the variance of investment well, it does not fit the variance of energy loss nor rate of return well. There are clear reasons for this. Investment is

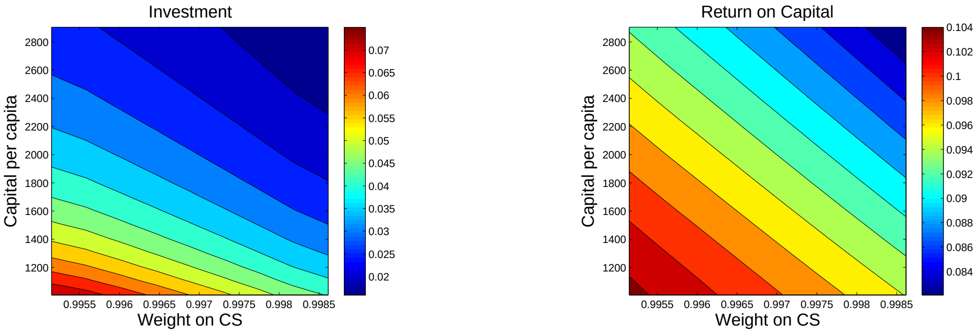

Figure 2: Investment policy of utility and rate of return policy of regulator

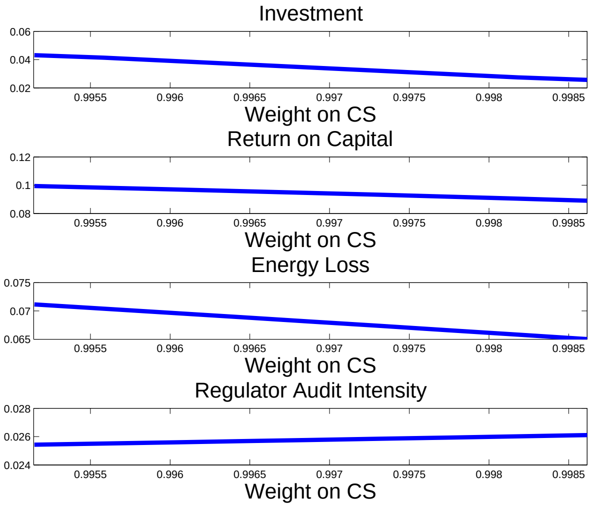

Figure 3: Investment policy of utility and rate of return policy of regulator

subject to a random shock in the model whose variance we estimate. The estimated variance allows the model to fit this second moment. We did not include shocks for energy loss nor rate of return. The reason is computational, as discussed in the previous section. Incorporating more stochastic processes into the estimation was computationally infeasible.

Table 7: Model Fit

Moment	Data	Model
Mean Investment	0.0500	0.0509
Mean Energy Loss	0.0675	0.0674
Mean Rate of Return	0.0963	0.0938
Standard Deviation of Investment	0.0278	0.0341
Standard Deviation of Energy Loss	0.0223	0.0023
Standard Deviation of Rate of Return	0.0133	0.0046

Empirical Identification: Parameter estimates are sometimes intuitively linked to specific features of the data. The sources of empirical identification for our model parameters can be well-understood by analyzing how parameter estimates change if certain moments of the data were to change. Here we describe the most important results on the relationships between model parameters and moments in the data. In Section 5 of the supplementary material, we provide details of such an analysis using the notions of sensitivity and sufficiency as in Gentzkow and Shapiro (2013), and present a table (Table S.6) that documents the results described below.

The effort cost parameter, γ_e, is sensitive to the mean of effort estimated from the data. The relationship is negative, i.e., higher effort in the data leads to lower estimates of effort cost. The quadratic investment cost parameter, η, is most sensitive to mean investment in the data. The coefficient of the error term in investment, σ_i, is sensitive to the standard deviation of investment. The market return adjustment cost, γ_r, is most sensitive to the mean rate of return in the data.

Parameters a_1 and a_2 are sensitive to the regressions of effort and rate of return on political variables as well as the standard deviations of rate of return and effort. These relationships provide a direct link between the regression results in Section 2.3 and the estimates of our non-linear dynamic model. We estimate that conservative regulators place more weight on utility profits than liberal regulators. It is because, in the model, regulators who place more weight on utility profits grant higher returns and engage in less auditing which leads to less effort and more energy loss, and in the data we observe higher rates of return and more energy loss with conservative regulators.

6 Counterfactual Experiments

We perform three sets of counterfactual experiments: (1) alternative rate of return policies by the regulator, including endowing the regulator with a commitment device, (2) alternative auditing policies for the regulator, and (3) alternative regulatory commission design, including minority party representation. In the first set, we explore a full commitment benchmark and setting the rate of return policy equal to the most conservative regulator's policy. In the second, we explore maximal auditing by the regulator and setting the audit policy equal to the most liberal regulator's policy. Thus, each set explores a theoretical benchmark and partisan extreme. The key intuition is that conservative environments reduce the problem of time inconsistency, while liberal environments reduce the problem of asymmetric information. Finally, in the third set, we explore enforcing minority representation which limits the degree to which a commission can swing to one partisan extreme or the other, and a perfectly centrist commission.

6.1 Rate of Return Policies including Commitment

As a theoretical benchmark, we solve for the regulator's optimal policy when it can credibly commit to future rates of return. This idea is analogous to Taylor's rule on monetary policy (Taylor (1993)), which stipulates the amount of change in the nominal interest rate in response to changes in inflation and output. Theoretically, commitment should lead to higher rates of return and higher investment by overcoming the fear of regulatory hold-up. Our results in Table 8 confirm and quantify the importance of this intuition.

We model commitment by changing the timing of actions in the dynamic game. In the commitment counterfactual, the regulator first chooses a rate of return policy that specifies r in each state (k,α). This policy is then held fixed. The utility solves a single agent problem conditional on this policy. To make this problem computationally tractable, we constrained the regulator's problem so that their commitment policy must be a scalar multiple of their equilibrium policy from the estimated MPE. Furthermore, we hold the audit policy fixed at the estimated equilibrium audit policy. These two restrictions reduce the commitment problem to a single dimensional optimization problem. We evaluate the commitment policy by averaging over different regulator preferences according to the ergodic distribution implied by the estimated Markov process for α.

In a world where the regulator could credibly commit to future rates of return ("Full Commitment"), the adjudicated rate of return is 14 percent higher than in the baseline. In every state, investment rises substantially.[58] The steady state mean capital level rises by 59%. Mean investment

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[58] In Table 8, Investment w.r.t. Baseline is the un-weighted mean ratio of investment across states. The steady state means of investment (row 6) for baseline and commitment are closer to each other because the steady state capital is higher under commitment, and investment is decreasing in capital.

Table 8: Results of Rate of Return Counterfactual Experiments

	Baseline	Conservative Rate		Full Commitment	
			Δ %		Δ %
Mean Return on Capital	0.100	0.103	3.24%	0.108	8.36%
Return Policy w.r.t. Baseline	1.000	1.062	6.20%	1.140	**14.00**%
SD Return on Capital	0.003	0.001	-55.57%	0.004	15.79%
Mean Audit	0.974	0.974	-0.01%	0.974	-0.01%
SD Audit	0.000	0.000	-3.20%	0.000	-14.01%
Mean Investment Rate	0.052	0.056	7.62%	0.051	-2.93%
SD Investment Rate	0.007	0.007	5.96%	0.006	-8.46%
Investment Policy w.r.t. Baseline	1	1.308	30.80%	1.459	**45.90**%
Mean Energy Loss	0.069	0.068	-0.92%	0.068	-1.09%
SD Energy Loss	0.002	0.002	-3.20%	0.002	-14.01%
Utility Value Per Capita	1616.012	2131.540	31.90%	2981.877	84.52%
Consumer Value Per Capita	539558.700	539619.620	0.01%	539291.004	-0.05%
Total Welfare	541174.712	541751.160	0.11%	542272.882	0.20%
Steady State Capital Per Capita	1179.306	1462.226	23.99%	1880.266	**59.44**%
SAIDI (average outages)	144.687	134.416	-7.10%	119.240	**-17.59**%

Note: Different rates of change (Δ%) in summary statistics can be associated with seemingly identical numbers due to round-up errors.

is lower than under the baseline because the system spends more time at higher capital levels, and investment is decreasing in capital. Consumers would pay higher prices and receive service with around 25.4 fewer outage minutes per year, or an 18% improvement in reliability. Utility value increases dramatically while consumer value slightly decreases. That consumer value decreases is natural when thinking about commitment. Under commitment, the regulator finds itself in states of the world where it would like to decrease the rate of return to increase consumer surplus, as it would in a Markov Perfect Equilibrium.[59]

The main driver of this result (commitment increasing capital) is that the possible improvements in reliability from capital additions are cheap compared to the their estimated benefit at current capital levels. When the regulator can commit to future policies, it can induce the utility to invest up to the point where the marginal benefit of investment in reliability improvements equals the marginal cost of investment in capital. While there are not heterogenous types of capital in our model, under-investment can be understood as a combination of too much aging infrastructure which has not been replaced and too little investment in new technologies such as automated switching systems.[60]

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[59] That consumer welfare decreases slightly may also be driven by our restriction to regulator policies which are a scalar multiple of the Markov Perfect Equilibrium policy.

[60] We have abstracted from investments by distribution utilities in new technologies, such as accommodating dis-

Higher rates and investment do not occur in the Markov Perfect Equilibrium because of the fear of regulatory hold-up. Absent commitment by the regulator, the utility won't make large investments because once the investments are sunk, the regulator's incentives lead to adjudicating low rate of return which do not adequately compensate the utility for the investments. Realizing this incentive for regulatory hold-up, the utility does not invest in the first place. Such anticipation by the utility implies that regulatory hold-up can be a real impediment to welfare without one ever observing actual instances of large investments followed by decreases in regulated rates.

Actions that the government can take in reality for commitment include passing legislation for large investment programs. For example, the legislature in Illinois enacted legislation in 2011 to force the regulator to pay a return on new investments in the electricity distribution infrastructure. The *Energy Infrastructure Modernization Act* in Illinois authorized \$2.6 billion in capital investment for Commonwealth Edison, the electricity distributor in Chicago. One of the main explicit goals is reducing SAIDI by 20 percent, which is close to our model's predicted reliability improvement under commitment. Commonwealth Edison praised the act as "[bringing greater stability to the regulatory process to incent investment in grid modernization." (McMahan (2012)). In Missouri, the *Infrastructure Strengthening and Regulatory Streamlining Act* was proposed with the same justification. This legislation would have required Ameren Missouri to increase its capital base by 14.5% targeted at capital investments that improve distribution reliability. These legislative initiatives bypass the traditional regulatory process conducted by rate cases with a more rigid legislative regulatory process.

The implied magnitudes in this counterfactual are sensitive to the value of reliability. However, the qualitative outcome that regulated rates of return and investment are too low is not. In Section 2 of the supplementary material, we tabulate how changes in the estimated value of reliability and changes in the estimated cost of improving reliability by capital investment would approximately affect the degree of estimated under-investment.[61] If either the aggregate value of reliability improvements from observed levels were half of the estimated value, or if the coefficient we estimate in the reliability-capital regression were two-thirds the estimated value, then we would estimate that the average electricity distribution system has the appropriate capital level.

In "Conservative Rate" in Table 8, we constrain regulators to choose rates of return equal to or greater than those chosen by the most conservative regulator. This constraint binds in all states, so equilibrium rates of return are equal to those of the most conservative regulator. Interestingly, this policy does slightly better than the constrained full commitment policy on consumer welfare, though the results are similar. Recall our full commitment policy is constrained to be a scalar

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tributed generation from household solar power or installation of smart-meters whose major benefits do not arise from reliability improvements.

[61] We vary the fraction of industrial consumers and commercial consumers, the corresponding valuations of those consumers for improvements in reliability, and the technological rate at which capital improves reliability. The results on under-investment are robust to moderate to large changes in these estimates.

Table 9: Results of Auditing Policy Counterfactual Experiments

	Baseline	Most Liberal		Maximal Audit	
			Δ %		Δ %
Mean Return on Capital	0.100	0.100	-0.09%	0.100	-0.03%
SD Return on Capital	0.003	0.003	1.83%	0.003	2.66%
Mean Audit	0.974	0.974	-0.04%	0.967	-0.79%
SD Audit	0.000	0.000	-96.92%	0.000	-100.00%
Mean Investment Rate	0.052	0.052	-0.16%	0.052	-0.10%
SD Investment Rate	0.007	0.007	1.20%	0.007	1.59%
Mean Energy Loss	0.069	0.065	-5.22%	0.000	-100.00%
SD Energy Loss	0.002	0.000	-96.92%	0.000	-100.00%
Utility Value Per Capita	1616.012	1609.517	-0.40%	1602.792	-0.82%
Consumer Value Per Capita	539558.700	539734.130	0.03%	543068.318	0.65%
Total Welfare	541174.712	541343.647	0.03%	544671.110	0.65%

Note: Different rates of change (Δ%) in summary statistics can be associated with seemingly identical numbers due to round-up errors.

multiple of the MPE rate of return policy. Because of different regulator political ideologies, the MPE rate of return policy assigns different rates of return for the same capital level depending on the commission make-up. The minimum rate of return policy eliminates these distortions. The results indicate that tilting towards a conservative regulator in areas with poor reliability is a possible substitute for commitment policies.

6.2 Auditing Policies

We now switch focus to the problem of asymmetric information which manifests itself as energy loss. In Table 9, we consider a uniform implementation of the maximum audit intensity estimated from our data ("Most Liberal Audit").[62] We also consider the theoretical benchmark of maximal audit policy ("Maximal Audit") which maximally incentivizes the utility to reduce energy loss.

Under the audit policy set at the most liberal regulator's level, energy loss decreases by about five percent (half a percentage point of the total energy distributed). This implies that society could consume the same amount of electricity with half a percentage point less generation, saving on the order of 1 billion dollars per year. Maximal auditing leads to zero energy loss. The utility is worse off as it suffers a dis-utility from maximum effort. However, the improvement in consumer value

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[62] In theory, there is no obvious linkage between the audit intensity in our model and specific auditing practices. However, the most stringent auditing practices could be studied and replicated. For example, the government can set up a rule by which the regulatory commission is required to allocate a certain amount of budget in monitoring utility behavior in power procurement.

dominates the loss in utility profits. As a result, total welfare increases.[63]

6.3 Commission Design and Minority Representation

Let us now consider imposing a restriction on the influence of politics in regulation. Specifically, we consider a rule which requires that no more than a certain fraction of regulatory commissioners can be from the same party. This rule is already in place in some states. The bound is typically three commissioners out of five. For example, in Connecticut, no more than three among five can be from the same political party; in Colorado, no more than two among three can be from the same political party. We simulate such a rule ("Minority Representation") with a *mean-preserving shrinkage* of the Markov process governing the evolution of the regulator's weight on consumer surplus. We reduce the standard deviation of the α process to 40% of the baseline which corresponds to the implied reduction in α if the fraction of Republican commissioners were bounded by 0.4 and 0.6 in the data. Table 10 shows the results. By construction, this policy has little effect on *mean* outcomes. What determines the mean level of investment is the expected stream of future returns which is not affected by this policy. However, this policy has a significant effect on *second moments* of rates of return and investment. Our result would be useful in designing and assessing policy tools to reduce variation in the quality and efficiency of energy distribution over time and across states.[64] We also consider a regulatory commission at the mean with zero variance as a theoretical benchmark ("Centrist Commission" in Table 10). The results are similar to the minority representation counterfactual, but with even greater decreases in the variance of observable outcomes.

6.4 Discussion: Commitment, Auditing, and Political Environments

Both time inconsistency and asymmetric information have quantitatively large effects on electric power distribution. Time inconsistency leads to under-investment in capital. Asymmetric information leads to too much energy loss. The results suggest that jurisdictions where reliability is poor might benefit from appointing more conservative regulators whereas jurisdictions with good reliability but large energy loss might benefit from appointing more liberal commissioners.

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[63] This particular counterfactual needs to be taken with a grain of salt, because such a policy is out of the range of energy loss in the data, and functional form assumptions on the cost of effort and transformation of effort into energy loss are less credible. It is physically impossible to have zero energy loss.

[64] A more complicated version of our model can also predict a larger influence of the minority representation requirement. We have aggregated many different utilities when estimating the parameters of the utility-regulator model. In particular, the Markov process governing the weight on consumer surplus is assumed to be the same across utilities for computational tractability. In reality, more extreme states would have different means and less variance than we currently estimate. In such a case, minority representation rule could have more pronounced effects on observable outcomes.

Table 10: Results of Commission Design Counterfactual Experiments

	Baseline	Minority Representation		Centrist Commission	
			Δ %		Δ %
Mean Return on Capital	0.100	0.100	0.09%	0.100	0.05%
SD Return on Capital	0.003	0.002	-50.15%	0.001	-82.08%
Mean Audit	0.974	0.974	0.00%	0.974	0.00%
SD Audit	0.000	0.000	-56.80%	0.000	-93.95%
Mean Investment Rate	0.052	0.053	0.41%	0.053	0.45%
SD Investment Rate	0.007	0.003	-48.98%	0.003	-49.47%
Mean Energy Loss	0.069	0.069	0.05%	0.069	0.01%
SD Energy Loss	0.002	0.001	-56.80%	0.000	-93.95%
Utility Value Per Capita	1616.012	1615.853	-0.01%	1615.988	0.00%
Consumer Value Per Capita	539558.700	539571.893	0.00%	539573.974	0.00%
Total Welfare	541174.712	541187.746	0.00%	541189.962	0.00%

Note: Different rates of change (Δ%) in summary statistics can be associated with seemingly identical numbers due to round-up errors.

7 Conclusion

This paper quantifies two fundamental issues in natural monopoly regulation, time inconsistency and asymmetric information, and explores their interaction with regulators' political ideology, focusing on electricity distribution. We estimate that there is under-investment in electricity distribution capital. We then document that more conservative political environments lead to higher regulated rates of return and less static productivity as measured by the amount of electricity purchased per unit of electricity delivered. We explain these facts using a model of a dynamic game between a regulator and a utility. The regulator sets the utility's rate of return and audits the utility's effort each period. The utility chooses investment and managerial effort each period. Conservative regulators, who place relatively more weight on utility profits, grant higher rates of return which lead to more investment. This behavior is advantageous for society in light of under-investment due to the time inconsistency problem. However, these regulators also engage in less auditing which leads to less managerial effort by the utility which exacerbates the asymmetric information problem.

Using estimates of the model, we simulate and quantify welfare gains in the benchmark environments where the above two issues are mitigated. The time-inconsistency dominates the asymmetric information problem, though both are important. One policy suggestion is to tilt towards more conservative regulators in territories with poor electricity reliability, and tilt towards more liberal regulators in territories with good reliability.

Future research could go in two directions. One direction would be to improve the model by incorporating more heterogeneity in both demand and supply, for example by distinguishing between industrial and residential consumers and allowing for heterogeneity in the reliability benefits of capital across geographic conditions. The second direction would be to examine commitment and asymmetric information in other domains of regulation. Natural gas distribution, banking, and health insurance are all large sectors subject to regulation by political agents.

References

Abito, Jose Miguel, “Welfare Gains from Optimal Pollution Regulation,” 2013. Working Paper.

Alt, Jr. Lowell E., *Energy Utility Rate Setting: A Practical Guide to the Retail Rate-Setting Process for Regulated Electric and Natural Gas Utilities*, lulu.com, 2006.

Armstrong, Mark and David EM Sappington, “Recent Developments in the Theory of Regulation,” *Handbook of Industrial Organization*, 2007, *3*, 1557–1700.

Athey, Susan, Andrew Atkeson, and Patrick J Kehoe, “The optimal degree of discretion in monetary policy,” *Econometrica*, 2005, *73* (5), 1431–1475.

Averch, Harvey and Leland L Johnson, “Behavior of the firm under regulatory constraint,” *The American Economic Review*, 1962, pp. 1052–1069.

Bajari, Patrick, C. Lanier Benkard, and Jonathan Levin, “Estimating Dynamic Models of Imperfect Competition,” *Econometrica*, September 2007, *75* (5), 13311370.

Baron, David P and David Besanko, “Regulation, Asymmetric Information, and Auditing,” *The RAND Journal of Economics*, 1984, pp. 447–470.

_ and _ , “Commitment and Fairness in a Dynamic Regulatory Relationship,” *Review of Economic Studies*, 1987, *54* (3), 413–436.

Baron, David P. and Roger B. Myerson, “Regulating a Monopolist with Unknown Costs,” *Econometrica*, 1982, *50* (4), 911–930.

Beecher, Jan, “Commissioner Demographics 2013 (IPU Research Note),” 2013. http://ipu.msu.edu/research/pdfs/IPU Commissioner Demographics (2013).pdf.

Bernstein, Mark A. and James Griffin, “Regional Differences in the Price-Elasticity of Demand for Energy,” *RAND Corporation Technical Report*, 2005.

Besley, Timothy and Stephen Coate, “Elected Versus Appointed Regulators: Theory and Evidence,” *Journal of the European Economic Association*, Sep. 2003, *1* (5), 1176–1206.

Brocas, Isabelle, Kitty Chan, and Isabelle Perrigne, “Regulation under Asymmetric Information in Water Utilities,” *The American Economic Review P& P*, 2006, *96* (2), 62–66.

Brown, Richard E., *Electric Power Distribution Reliability*, CRC Press, 2009.

Coase, Ronald H., “Durability and Monopoly,” *Journal of Law and Economics*, 1972, *15*, 143.

Dal Bó, Ernesto and Martín A. Rossi, "Corruption and Inefficiency: Theory and Evidence from Electric Utilities," *Journal of Public Economics*, 2007, *91* (5-6), 939–962.

Economic Development Research Group, *Failure to Act: The Economic Impact of Current Investment Trends in Electricity Infrastructure.* American Society of Civil Engineers 2011. http://www.asce.org/uploadedFiles/Infrastructure/Failure_to_Act/SCE41%20report_Final-lores .pdf.

Formby, John P., Banamber Mishra, and Paul D. Thistle, "Public Utility Regulation and Bond Ratings," *Public Choice*, July 1995, *84* (1/2), 119–136.

Gagnepain, Philippe and Marc Ivaldi, "Incentive Regulatory Policies: The Case of Public Transit Systems in France," *The RAND Journal of Economics*, 2002, pp. 605–629.

Gentzkow, Matthew and Jesse Shapiro, "Measuring the Sensitivity of Parameter Estimates to Sample Statistics," 2013. Working Paper.

Gilbert, Richard J and David M Newbery, "The Dynamic Efficiency of Regulatory Constitutions," *The RAND Journal of Economics*, 1994, pp. 538–554.

Growitsch, Christian, Tooraj Jamasb, and Michael Pollitt, "Quality of service, efficiency and scale in network industries: an analysis of European electricity distribution," *Applied Economics*, 2009, *41* (20), 2555–2570.

Hempling, Scott and David Boonin, "Overview of Regulatory Incentives in the Context of Public Policy Goals: Prepared for the Colorado Public Utilities Commission," *National Regulatory Research Institute*, 2008.

Holmstrom, Bengt and Paul Milgrom, "Aggregation and linearity in the provision of intertemporal incentives," *Econometrica*, 1987, pp. 303–328.

Ito, Koichiro, "Do Consumers Respond to Marginal or Average Price? Evidence from Nonlinear Electricity Pricing," *American Economic Review, forthcoming*, 2013.

Joskow, Paul and Jean Tirole, "Reliability and competitive electricity markets," *The Rand Journal of Economics*, 2007, *38* (1), 60–84.

Joskow, Paul L, "Inflation and environmental concern: Structural change in the process of public utility price regulation," *JL & Econ.*, 1974, *17*, 291.

Joskow, Paul L., "Incentive Regulation in Theory and Practice: Electric Distribution and Transmission Networks," in Nancy Rose, ed., *Economic Regulation and its Reform: What Have We Learned?*, University of Chicago Press, 2007. http://econ-www.mit.edu/files/1181.

Kydland, Finn E and Edward C Prescott, "Rules Rather than Discretion: The Inconsistency of Optimal Plans," *The Journal of Political Economy*, 1977, pp. 473–491.

LaCommare, Kristina Hamachi and Joseph H. Eto, *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers.* Ernest Orlando Lawrence Berkeley National Laboratory, U.C. Berkeley 2004.

_ and _ , *Cost of Power Interruptions to Electricity Consumers in the United States (U.S.).* Ernest Orlando Lawrence Berkeley National Laboratory, U.C. Berkeley 2006.

Laffont, Jean-Jacques and Jean Tirole, "A Theory of Incentives in Procurement and Regulation," 1993.

Leaver, Clare, "Bureaucratic Minimal Squawk Behavior: Theory and Evidence from Regulatory Agencies," *American Economic Review*, 2009, *99* (3), 572–607.

Levy, Brian and Pablo T Spiller, "The Institutional Foundations of Regulatory Commitment: A Comparative Analysis of Telecommunications Regulation," *JL Econ. & Org.*, 1994, *10*, 201.

Lewis, Gregory and Patrick Bajari, "Moral Hazard, Incentive Contracts, and Risk: Evidence from Procurement," *NBER Working Paper*, 2013.

Lewis, Tracy R and David EM Sappington, "Oversight of Long-term Investment by Short-lived Regulators," *International Economic Review*, 1991, pp. 579–600.

Lim, Claire S.H. and James M. Snyder, "Elections and the Quality of Public Officials: Evidence from U.S. State Courts," 2014. Working Paper.

Lyon, Thomas P and John W Mayo, "Regulatory Opportunism and Investment Behavior: Evidence from the U.S. Electric Utility Industry," *The RAND Journal of Economics*, 2005, pp. 628–644.

McCarty, Nolan, Keith T. Poole, and Howard Rosenthal, *Polarized America: The Dance of Ideology and Unequal Riches*, The MIT Press, 2008.

McMahan, Michael, *Energy Infrastructure Modernization Act Transforming Illinois Electric Grid* 2012. http://www.ncsl.org/documents/energy/McMahan_PPT.pdf.

Mermelstein, Ben, Volker Nocke, Mark Satterthwaite, and Michael Whinston, "Internal versus External Growth in Industries with Scale Economies A Computational Model of Optimal Merger Policy," 2012. Working Paper.

Mirrlees, James A, "An Exploration in the Theory of Optimum Income Taxation," *Review of Economic Studies*, 1971, *38* (2), 175–208.

Misra, Sanjog and Harikesh S Nair, "A Structural Model of Sales-Force Compensation Dynamics: Estimation and Field Implementation," *Quantitative Marketing and Economics*, 2011, *9* (3), 211–257.

Nillesen, P.H.L. and M.G. Pollitt, "Ownership unbundling in electricity distribution: empirical evidence from New Zealand," *Review of Industrial Organization*, 2011, *38* (1), 61–93.

Pakes, Ariel, Michael Ostrovsky, and Steven Berry, "Simple estimators for the parameters of discrete dynamic games (with entry/exit examples)," *The RAND Journal of Economics*, 2007, *38* (2), 373–399.

Poole, Keith and Howard Rosenthal, *Congress*, Oxford University Press, 2000.

Rogoff, Kenneth, "The Optimal Degree of Commitment to an Intermediate Monetary Target," *Quarterly Journal of Economics*, 1985, *100* (4), 1169–1189.

Ryan, Stephen P, "The costs of environmental regulation in a concentrated industry," *Econometrica*, 2012, *80* (3), 1019–1061.

Squire, Peverill and Eric R.A.N. Smith, "The Effect of Partisan Information on Voters in Non-Partisan Elections," *Journal of Politics*, 1988, *50* (1), 168–179.

Taylor, John B, "Discretion versus Policy Rules in Practice," in "Carnegie-Rochester Conference Series on Public Policy," Vol. 39 Elsevier 1993, pp. 195–214.

Timmins, Christopher, "Measuring the Dynamic Efficiency Costs of Regulators' Preferences: Municipal Water Utilties in the Arid West," *Econometrica*, 2002, *70* (2), 603–629.

U.S. Supreme Court, "Federal Power Commission v. Hope Gas Co.," 1944, *320* (No. 34), 591.

Wolak, Frank A., "An Econometric Analysis of the Asymmetric Information, Regulator-Utility Interaction," *Annales d'Economie et de Statistique*, 1994, *34*, 13–69.