The Dynamics of Natural Monopoly Regulation and Political Environments

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Abstract

This paper studies time inconsistency, asymmetric information, and political ideology in natural monopoly regulation of electricity distribution companies. Empirically, more conservative political environments have higher regulated rates of return and worse operational efficiency as measured by electricity lost in distribution. Capital investment improves reliability in a cost effective manner. We estimate a dynamic game theoretic model of utility regulation featuring investment and asymmetric information. Under-investment due to time inconsistency is severe. Conservative regulators improve welfare losses due to time inconsistency, but worsen losses due to asymmetric information.

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

JEL Classification: D72, D78, L43, L94

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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), Gilbert and Newbery (1994)) 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, which we label as "time inconsistency" and "asymmetric information," make it difficult, if not impossible, for regulation to achieve 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 sector with yearly revenues of $320 billion.

The time inconsistency problem in this context is regulatory hold-up: the regulator would like to promise a fair return on irreversible investments *ex ante*, but after the investments are sunk, the regulator has no reason to pay the promised return (Baron and Besanko (1987), Gilbert and Newbery (1994), Lewis and Sappington (1991)). 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)).[1]

The central insight of this paper is that regulatory environments which place a relatively higher weight on utility profits than 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 that 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 US Congressmen vote, and within-state time variation in the party affiliation of state regulatory commissioners. Both of the core empirical results hold using either source of variation.

We explain these core empirical facts 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. When regulators place more weight on utility profits, they adjudicate higher regulated rates of return but also engage in less auditing.

[1] Adverse selection is also at play in this literature. This paper focuses on moral hazard.

We estimate the model's parameters using a two-step estimation procedure for dynamic games 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 the stronger investment incentives can overcome 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.

Appropriate rules and design of institutions could break the observed tension between providing incentives to invest and incentives to operate efficiently. We counterfactually simulate outcomes when (1) the regulator can commit to future rates of return, (2) minimum auditing requirements for the regulator, and (3) when the regulatory board must maintain a minimum level of minority representation. We find that regulators would like to substantially increase rates of return to provide incentives for capital investment. Tilting the regulatory commission towards conservatives, analogous to the idea in Rogoff (1985) for central bankers, can help replicate this outcome. 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, in addition to the long theoretical literature on natural monopoly regulation cited earlier that models time inconsistency and asymmetric information in the regulator-utility relationship, there are a handful of empirical monopoly regulation studies. 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 focusing on regulation of private water utilities. More recently, Gagnepain and Ivaldi (2002) and Abito (2013) use static models of regulator-utility asymmetric information to study transportation service in France and environmental regulation of electric power generation in the United States, respectively. This paper adds a dynamic investment problem in parallel to the asymmetric information problem. The investment portion of this paper is related to Lyon and Mayo (2005) who study the possibility of regulatory hold-up in power generation, and conclude that observed capital disallowances during their time period do not reflect regulatory hold-up. Finally, our paper is related to static production function estimates for electricity distribution such as Growitsch et al. (2009) and Nillesen and Pollitt (2011).

More broadly, economic regulation is an important feature of many sectors in addition to electric power distribution: 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[2], a state insurance commissioner, a municipal government manager, 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. This paper provides empirical evidence that political ideology affects regulatory decisions and traces out the implications 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. [3]

The rest of the paper is organized as follows. Section 2 introduces the institutional background of electricity rate regulation and provides a preliminary analysis of the data. Section 3 specifies the model, and Section 4 describes its identification and estimation. Section 5 presents the estimation results. Section 6 discusses our counterfactual experiments, and Section 7 concludes.

2 Institutional Background, Data, and Preliminary Analysis

We first describe the electric power distribution industry and its regulation. We then define the notions of asymmetric information and time inconsistency in this setting and discuss the previous literature on these issues. We then describe the data sets we use and key summary statistics. Finally, we present the core 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 and between reliability and investment.

[2]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.

[3]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.

2.1 Institutional Background

The electricity industry is typically divided into three levels of production: generation, transmission, and distribution[4]. Generation encompasses the transformation of raw materials into electricity. Transmission encompasses the delivery of electricity from generation plant to distribution substation. Distribution is the final leg by which electricity is delivered locally to residences and business. 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. This paper focuses on distribution. Generation of electricity has been deregulated in many countries and US states. Distribution is almost universally considered a natural monopoly that is regulated in the U.S. by state "Public Utility Commissions" (PUC's)[5]. The commission's mandate is to regulate prices and utility behavior to ensure reliable and least costly delivery of electricity to end users.

PUC's and utilities engage in periodic "rate cases" as well as more frequent rule-making proceedings. 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 may also formally specify targets that the utility must meet for investments, maintenance, customer service, or reliability. 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 US is generally a hybrid of the theoretical extremes of cost of service regulation and price cap regulation. Under cost of service regulation, a utility is granted rates that earn it a fair rate of return on the capital that it invests and the operating costs it incurs. Under price cap regulation, a utility's prices are capped indefinitely. Cost of service regulation can lead too much investment and too high costs from a social point of view. Price cap regulation, on the other extreme, places strong incentives on the utility to reduce investment and costs, as it keeps such reductions for itself. PUC's in the US have converged on a system of price cap regulation with periodic resetting to reflect changes in cost of service as detailed in Joskow (2007).

In practice, this model of regulation requires the regulator to determine a revenue requirement for the utility. The price cap is then set to generate the revenue requirement. The revenue requirement must be high enough so that the utility can cover 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 potentially 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.

Our model will replicate the basic structure of the regulatory process in U.S. electricity distri-

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

[5]Also known as "Public Service Commissions," "State Utility Boards", or "Commerce Commissions".

bution. 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 some other features of the actual regulator-utility dynamic relationship. We will ignore financing constraints and capital structure. We will assume that a rate case happens every period. In reality, rate cases are less frequent. Their timing is also endogenous in that either the utility or regulator can initiate a rate case. We have assumed that the outcome of a rate case can be summarized by the regulated rate of return and an auditing intensity. In reality, rate case settlements have other outcomes including but not limited to: prescriptions for specific investments, prescriptions for specific actions to be taken by the utility, 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 United States.

2.2 Data

Characteristics of the Political Environment: 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).[6] We aggregate congressmen's Nominate score for each state-congress, separately for the Senate and the House of Representatives. This yields two measures

[6] 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	967253	1532272	0	12090878	3785
Revenues from					
Residential Consumers	414155	679508	0	6493585	3785
Commercial Consumers	352699	660560	0	6097635	3785
Industrial Consumers	186194	265691	0	2345168	3785
Net Value of Distribution Plant	1059400	1358253	-446518	13651183	3844
Average Yearly Addition to Distribution Plant between Rate Cases	0.0658	0.0181	0.0162	0.1612	511
Average Yearly Net Addition to Distribution Plant between Rate Cases	0.0559	0.0223	-0.0935	0.1647	511
O&M Expenses	57249	68533	0	648493	3867
Energy Loss (Mwh)	1236999	1403590	-7486581	1.03e+07	3796
Reliability Measures					
SAIDI	137.25	125.01	4.96	3908.85	1844
SAIFI	1.48	5.69	0.08	165	1844
CAIDI	111.21	68.09	0.72	1545	1844
Bond Rating	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 Base	9.12	1.3	5.04	14.94	729
Equity Ratio	45.98	6.35	16.55	61.75	729
Rate Change Amount	40828	91343	-300500	785333	731

Note: 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 (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.

[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.

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 "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.[7] As for the availability of ballot initiatives, we use the information provided by the Initiative and Referendum Institute.[8] We construct a dummy variable that takes value one if ballot proposition is available in the state.

Characteristics of Regulators: 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 for each state and in each year: the party affiliation of commissioners, the tenure of serving commissioners, and whether commissioners are appointed or elected. 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.

Utilities and the Electric Power Industry: We use three 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, and the PA Consulting Electric Reliability database.

FERC Form 1 is filed yearly by utilities which meet a certain size threshold. It details their balance sheet and cash flows on most aspects of their business. The key variables for our study are the value of electric distribution and transmission plant, operations and maintenance expenditures of distribution and transmission, 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 by the utility and energy delivered by the utility. We use energy loss as one measure of utility productivity. The average ratio of electricity lost through distribution and transmission to total electricity generated is 7% in the US over the past twenty years, which translates to roughly 25 billion dollars in 2011. Energy loss is determined by many factors. Some amount of loss is unavoidable. As electricity travels over wires and changes voltages, power is lost. The extent of these losses is partially controlled by the utility. Utilities have electrical engineers who specialize in power distribution. They deal with the efficient

[7] See http://www.ncsl.org/legislatures-elections/elections/campaign-contribution-limits-overview.aspx for details.
[8] See http://www.iandrinstitute.org/statewide_i%26r.htm

design, maintenance, and operation of power distribution systems. The configuration of the network of lines and transformers, the age and quality of transformers, the siting of incoming energy, and peak-load management are factors which affect energy loss which are partially controlled by management. In sum, energy loss is a measure of utility productivity which is a function of characteristics of the utility territory such as population density and weather, but also managerial skill and effort.

EIA Form 861 provides data by utility and state by year on sales and revenues by customer class (residential, commercial, industrial, or transportation). We use these to construct an average yearly price by utility and state for each customer class for the years 1990-2012.

The PA Consulting proprietary reliability database provides reliability metrics by utility by year. Much of the data is publicly available through various public utility commission archives. We use the measures of System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI) excluding major events.[9] SAIDI is equal to the sum of all customer interruption durations divided by the total number of customers, so the unit is minute. For example, if there are 2 customers, and customer 1 has one hour of interruption and customer 2 has two hours of interruption, the SAIDI would be equal to 90 minutes. 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. Since SAIDI is a measure of power outage, a high value of SAIDI implies low reliability.

Rate Cases: We acquired data on electric rate cases from the SNL Energy. The data is composed of total 731 cases on 144 utilities from 50 states, from 1990 to 2012. It includes four key variables on each rate case: return on equity, return on base, equity ratio, and the change in revenues approved. Panel D of Table 1 shows that all the four key variables have a large variation.

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.

[9]Major event definitions can vary over time and across utilities.

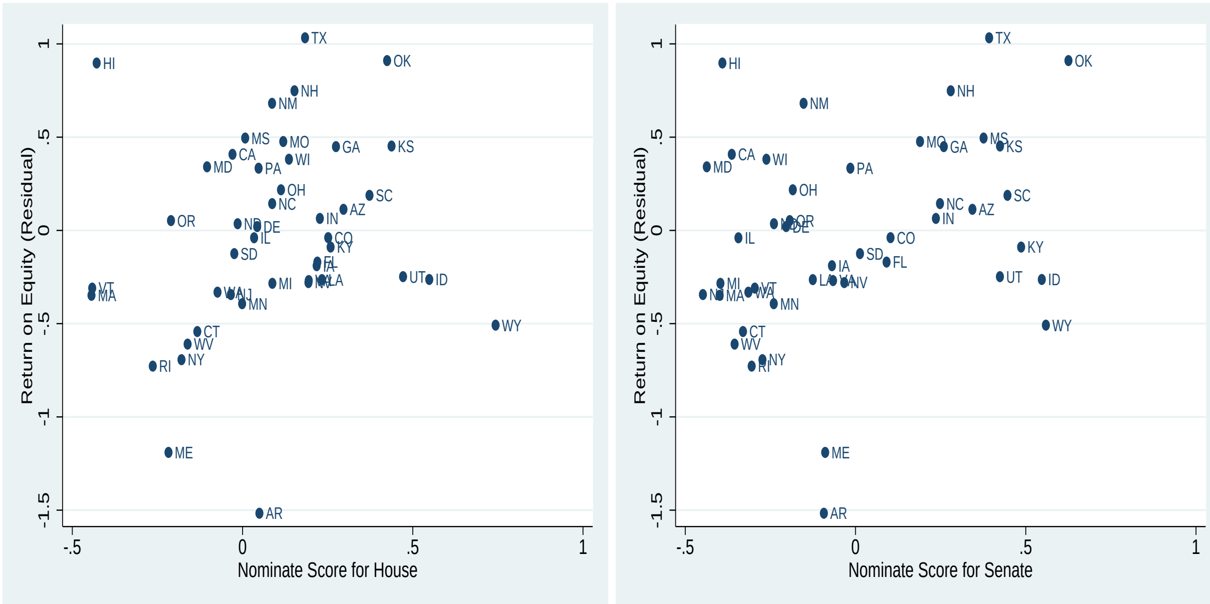

Figure 1: Relationship between Return on Equity and Political Ideology

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. Figure 1 shows scatter plots of return on equity and Nominate scores for 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.[10] Both panels of the figure show that regulators in states with conservative ideology tend to adjudicate high return on equity.

We also run regressions of return on equity on Nominate score and other features of political environments:

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

where x_{it} is a vector of demographic and financial covariates for utility i in year t, and γ_t are year fixed effects. Table 2 shows the results.[11]

Panel A uses Nominate score for the U.S. House (Columns (1)-(4)) and Senate (Columns (5)-

[10] 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.

[11] Equation (1) above is the specification of Column (6). 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				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
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

(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 (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[12], which is approximately 47% of the standard deviation in return on equity.[13]

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.[14] 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.[15] 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.

The results on the influence of other political variables are also noteworthy. We find that the influence of (no) restriction on campaign donation from corporations or the availability of ballot

[12]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 $0.706 * (.42 - (-.45)) \approx 0.61$.

[13]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.

[14]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.

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

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

Another interesting feature is the positive estimated effect of having elected regulators relative to appointed regulators. Our estimate implies that states with elected regulators is associated with higher level of profit adjudicated for utilities, which contrasts with several existing studies in the literature. 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.[16]

2.3.2 Return on Equity and Investment

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

We use two different measures of investment: the average yearly 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 addition to the distribution plant per year between rate case years as a proportion of the distribution plant in the preceding rate case year. [17] 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 fixed effects, $Return\ on\ Equity_{it}$ is the return on equity, and x_{it} is a set of demographic control variables.

[16] 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.

[17] Precisely, expenses are not a part of the conventional concept of investment, because it does not add to the value of the capital. However, it can still be regarded as a substitute for the investment in the distribution plant, because it also improves reliability of distribution.

Table 3: Regression of Investment on Return on Equity

Panel A: Average Yearly Addition to Distribution Plant				
Variable	(1)	(2)	(3)	(4)
Return on Equity	0.0028***	0.0028***	0.0037***	0.0037***
	(0.0007)	(0.0007)	(0.0010)	(0.0010)
Observations	510	509	510	509
R-squared	0.039	0.042	0.449	0.449
Utility FE	No	No	Yes	Yes
Demographic Controls	No	Yes	No	Yes
Panel B: Average Yearly Net Addition to Distribution Plant				
Variable	(1)	(2)	(3)	(4)
Return on Equity	0.0026**	0.0026***	0.0042***	0.0042***
	(0.0010)	(0.0010)	(0.0012)	(0.0012)
Observations	510	509	510	509
R-squared	0.022	0.035	0.387	0.387
Utility FE	No	No	Yes	Yes
Demographic Controls	No	Yes	No	Yes

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

The result 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 (8) shows that one percentage point increase in return on equity is associated with .42 percentage point increase in the value of distribution plant, which is approximately a quarter of a standard deviation of average yearly investment.[18]

2.3.3 Investment and Reliability

A utility's reliability is partially determined by actions the utility takes such as investing in new capital and hiring labor to upgrade and maintain the distribution system. Two concrete examples of actions a utility can take to increase its reliability are putting power lines underground and vegetation management[19]. We examine how changes in such expenditures affect realizations of reliability, by estimating regressions of the form:

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

where $SAIDI_{it}$ is our preferred measure of reliability 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 weather and storm related explanatory variables. In this regression as specified, 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. A prolonged period of stormy weather would decrease reliability and the utility would compensate by sending workers to repair the storm damage. Thus we would see poor reliability and high expenditure on operations and maintenance in the data. This correlation would bias our coefficient estimates on β_1 and β_2 towards positive infinity.[20] Animal damage (woodpeckers) to poles, automobile accidents into poles, and the interaction of rain levels with local flora are all unobservable factors simultaneously affecting reliability and operations expenditure.

The results from an OLS estimation of the above relationship confirm some of these suspicions. The coefficient on operations and maintenance is positive. However, the coefficient on distribution is negative, which can be taken as a lower bound on the magnitude given the direction of the biases. For the effect of operations and maintenance expenses, we would like to isolate secular changes

[18] We do not interpret these regression results as a causal relationship. For example, poor reliability of a utility may induce regulators to punish it by adjudicating low return on equity. And, the utility may invest heavily to avoid further punishment. Such a situation of reverse causality would cause a downward bias in estimating the causal effect of return on equity on investment. In Section 3, we explicitly model utilities' decision making process in investment, which addresses this issue.

[19] 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.

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

Table 4: The Influence of the Investment on Reliability

	Dependent Variable: SAIDI		Dependent Variable: log(SAIDI)	
Variable	(1)	(2)	(3)	(4)
Net Distribution Plant	-13.54*	-10.46**		
($ million)	(7.47)	(4.85)		
log(Net Distribution Plant)			-0.260*	-0.457***
($ million)			(0.155)	(0.142)
Observations	1,697	1,204	1,694	1,201
R-squared	0.399	0.629	0.744	0.761
Utility 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: Robust standard errors, clustered by state, in parentheses. *** $p<0.01$; ** $p<0.05$; * $p<0.1$

in budgeting by the utility rather than short term responses to weather events. We tried a variety of approaches to address concerns of operations and maintenance expenditure being endogenous. For example, we instrumented for operations and maintenance expenditure with mean wages by state and year for "Electrical Power-Line Installers and Repairers" occupation code 49-9051 from the Bureau of Labor Statistics Occupational Employment Statistics database. This instrument was not powerful enough to estimate precise effects of operations and maintenance expenditure.

2.3.4 Political Ideology and Utility Management: Reliability and Energy Loss

The preceding three subsections indicate one important channel through which political environments influence social welfare: improvement of reliability under conservative public service commissioners. On the other hand, conventional belief that conservatives' favoritism toward businesses relative to consumers imply a possibility that more conservative commissioners may aggravate potential moral hazard by monopolists. To take a balanced view on this issue, we investigate direct relationships between political ideology and *efficiency of utility management* as well as reliability. Our measure of 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.

Table 5 shows results of regressing log($SAIDI$) on *Republican Influence* using the following

Table 5: Republican Influence on Reliability

Dependent Variable: log(SAIDI)				
Variable	(1)	(2)	(3)	(4)
Republican Influence	-0.267**	-0.260**	-0.189*	-0.202*
	(0.106)	(0.110)	(0.109)	(0.117)
Observations	1,844	1,836	1,256	1,248
R-squared	0.083	0.202	0.144	0.283
Year FE	Yes	Yes	Yes	Yes
Demographic Controls	No	Yes	No	Yes
Weather Controls	No	No	Yes	Yes

Note: Robust standard errors, clustered by state, in parentheses. *** p<0.01; ** p<0.05; * p<0.1

specification[21]:

$$\log(SAIDI) = \alpha + \gamma_t + \beta_1 Republican\ Influence_{it} + \beta_2 x_{it} + \varepsilon_{it}$$

The results suggest that more conservative ideology is associated with better reliability.[22]

On the other hand, our analysis of energy loss suggests that conservative environment is also associated with more energy loss. We run 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 *energy loss* is the amount of energy loss by utility i in year t, x_{it} is a set of variables that affect energy loss, such as distribution capital, operation and management expenses, and the magnitude of sales. The results are shown in Table 6.

The values for energy loss are non-trivial. The average amount of energy loss is 7% of total production. We find that moving from more conservative to less conservative political environments can reduce energy loss by between 13% and 54%, which would imply between 1% to 3% less total energy generated for the same amount of energy ultimately consumed[23]. This is large. This result

[21] In this regression, we do not include utility fixed effects. The identification of a model with utility fixed effects would hinge on a spontaneous response in reliability to changes in political ideology, which is at odds with the mechanism of the effect we laid out above. It may take a few years for high return on equity adjudicated by conservative regulators to cause substantial increase in distribution capital and subsequent improvement in reliability. Therefore, regressions with utility fixed effects would not properly capture the influence of political ideology on reliability.

[22] We also ran regressions with Nominate scores as a measure of political ideology, and did not obtain any statistically significant results. Thus, we regard this only as a weak evidence on the relationship.

[23] We ran these specifications including peak energy demand to account for variance in load. The results are similar

Table 6: Regression of Log Energy Loss on Political Ideology

Dependent Variable: log(energy loss)						
Panel A: Nominate Score as a Measure of Ideology						
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Republican Influence	0.168***	0.118**	0.133**	0.133**	0.130**	0.130**
	(0.0539)	(0.0550)	(0.0580)	(0.0590)	(0.0592)	(0.0593)
log(Net Distribution Plant)			0.479***	0.458**	0.418**	0.417**
			(0.168)	(0.173)	(0.166)	(0.166)
log(Operations and Maintenance)				0.0725	0.0586	0.0581
				(0.0776)	(0.0778)	(0.0779)
log(Sales)					0.221	0.221
					(0.143)	(0.143)
Observations	3,282	3,282	3,272	3,272	3,263	3,261
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	No	No	No	No	No	No
Demographics	No	No	No	No	No	No
Sample Restrictions	Yes	Yes	Yes	Yes	Yes	No
Panel B: Republican Influence as a Measure of Ideology						
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Nominate Score	1.208**	1.208**	0.470*	0.587**	0.540**	0.540**
	(0.461)	(0.461)	(0.277)	(0.258)	(0.248)	(0.248)
log(Net Distribution Plant)			0.981***	0.711***	0.649***	0.649***
			(0.0346)	(0.104)	(0.113)	(0.113)
log(Operations and Maintenance)				0.307**	0.276**	0.276**
				(0.118)	(0.116)	(0.116)
log(Sales)					0.106*	0.106*
					(0.0540)	(0.0540)
Observations	1,765	1,765	1,761	1,761	1,761	1,761
R-squared	0.100	0.100	0.713	0.720	0.724	0.724
Utility-State FE	No	No	No	No	No	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather	Yes	Yes	Yes	Yes	Yes	Yes
Demographics	Yes	Yes	Yes	Yes	Yes	Yes
Sample Restrictions	Yes	Yes	Yes	Yes	Yes	No

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

implies that moving from a commission of zero Republican commissioners to all Republican commissioners would require 1% more electricity to be generated to deliver the exact same amount. 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 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 structurally estimate a model that incorporates both features.

3 Model

We specify an infinite-horizon dynamic game between a regulator and an electric distribution utility. Each period corresponds to one year.[24] The utility and the regulator discount future payoffs at rates β_u and β_R, respectively. We assume $\beta_R < \beta_u$, reflecting that regulators leave the commission frequently.[25]

The state space consists of the value of utility's capital k and the regulator's weight on consumer surplus versus profits, α.[26] 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.

Our notion of 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, i.e., the pass-through rate is 1. 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.

but for a slightly lower magnitude of the Nominate score.

[24] 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.

[25] The average tenure of regulators is around 5 years. The median is 3.9 years. See Beecher (2013) for details.

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

3.1 Consumer Demand System

We assume a simple inelastic demand structure. An identical mass of consumers of size Q is willing to pay up to a choke price $\bar{p}+\tilde{\beta}\log(k)$:

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

$\tilde{\beta}$ 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 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. This assumption of identical consumers has been employed in other recent studies of electricity reliability such as Joskow and Tirole (2007). 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 simple, but slows down estimation considerably.[27]

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. Explicitly:

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

where p_f is the materials cost which reflects the input cost of electricity,[28] 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.

[27] 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.

[28] 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. Thus, inclusion of 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.

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:

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

The first term is the utility, in dollars, enjoyed by consuming quantity Q of electricity and the second term is 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:

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

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 with extreme value distribution.[29] σ_i is its scale parameter. 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 employed elsewhere in estimating dynamic models of investment, for example in Ryan (2012).

Effort increases the productivity of the firm by reducing the amount of materials needed to deliver a certain amount of output. We assume effort is the only determinant of the materials cost which implies that capital does not affect materials. 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.

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 20) into the utility's per-period

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

payoff function simplifies the payoff function to

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

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:

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

The utility's optimal effort choice has an analytical expression which will be useful in estimation:

$$e^*(\kappa) = \frac{-(\kappa-1)p_f Q}{2\gamma_e}$$

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 payoff that the regulator enjoys is the geometric mean of expected discounted consumer welfare, or consumer value,[30] and the utility value function minus the cost of auditing and the cost of deviating from the market return.[31]:

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

where α is the weight the regulator puts on consumer welfare[32] 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 to be estimated.

CV is the value function for consumer surplus:

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

[30]This is employed in dynamic models of merger regulation such as Mermelstein et al. (2012).

[31]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.

[32]We use consumer value which is the expected discounted sum of consumer welfare.

By default the utility is reimbursed for its total electricity input cost. In many states, this is in encoded into a purchased power adjustment clause. However, the regulator can ex-post disallow pass-through if it deems the utility's procurement process imprudent. The regulator however incurs a cost for deviating from the default of full pass-through: $\gamma_\kappa(1-\kappa)^2$. The regulator must investigate, solicit testimony, and incur the possibility of legal challenges by the utility for disallowing the utility's electricity cost expenses. The further the regulator moves away from full pass-through of materials costs, the more cost it incurs. The interpretation as a moral hazard problem is that the 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 unobservable effort by the utility.

The term $\gamma_r(r-r^m)^2$ represents an adjustment cost for adjudicating a rate that deviates from a benchmark level such as the average return for utilities across the country. Such a term is necessary because a regulator who places all weight on utility profits would not be able in reality to adjudicate the implied rate of return on capital to deliver all the surplus to the utility. Consumer advocacy groups and lawmakers would point 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 by accepting arguments that the utility in question is more risky than others, 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 period payoff are similar in nature. They are both dis-utility 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,

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

where d is the Nominate score of the utility's state and *rep* is the fraction of commissioners in the state with Republican party affiliation, and the vector $\mathbf{a}$ are 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 functions are optimal given its value function and the regulator's policy functions.*
2. *The regulator's policy function are optimal given consumer value and 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, strategic 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.

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. 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 channel happens indirectly through the regulated rates that the regulator adjudicates from period to period.

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 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.[33]

The regulator's actions in both interactions are determined by the weight it places on consumer surplus versus utility profits. Intuitively, the utility likes high returns and weak auditing. Therefore,

[33] 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 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 particular 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 on the logit error in the utility's problem σ_i, and the mapping between state ideology and party affiliation of regulators to weight on consumer surplus versus utility profits, $\mathbf{a} = (a_1, a_2, a_3)$. We denote $\theta = (\gamma_e, \eta, \gamma_\kappa, \gamma_r, \sigma_i, \mathbf{a})$. We fix and calibrate some parameters outside the estimation routine to save on computational time. We fix the yearly discount rate of the utility at 0.96, the yearly discount rate of the regulatory commission at 0.7275.[34] We fix the capital depreciation rate at 0.049 which is the average level in our data. We set the 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. This is well above the maximum amount of loss in the data.

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 \$30,000.[35] We set the willingness-to-pay for improving reliability, as measured by SAIDI, by 2.5 percent[36] is \$107. 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 \$2.7 to avoid a 30 minute outage for residential consumers to \$435 for small commercial and industrial consumers to \$9,217 for medium to large commercial and industrial consumers. To get to \$107 for a 2.5 percent improvement in SAIDI, we assume 10 percent of consumers are medium to large commercial and industrial, 50 percent are small commercial and industrial, and 40 percent are residential. Then the average value of

[34]This reflects the average turn-over of public utility commissioners.

[35]The \$30,000 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.

[36]This corresponds to 2.82 minutes fewer of outage in a year on a mean of 113 minutes. This can also be interpreted as a reduction in the probability of an extended outage.

improving SAIDI by 30 minutes is \$1,140. We scale down by $\frac{2.82}{30}$ to assign a value of \$107 to a 2.82 minutes, or 2.5 percent, improvement in reliability.[37]

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 the equilibrium of the dynamic game numerous times. The estimation criterion 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, two of the policies, effort and regulatory auditing, are unobserved. Unobserved effort is a challenge in the empirical analysis of moral hazard problems (Misra and Nair (2011), Lewis and Bajari (2013)). If effort were easily observed, then contingent contracts could be written, and no moral hazard problem would exist. Second, one of the state variables, the regulator's weight on consumer surplus is not observed directly but a function of observed variables and model parameters. In both cases, the unobserved quantity can be derived as a function of model parameters and data.

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}, a return on capital r_{it}, a market size Q_{it}, a fraction of Republican utility commissioners rep_{it}, and a state DW-Nominate score d_{it}. The following list describes the steps for calculating the estimation objective function for a given set of model parameters. We then detail each step. The estimation routine evaluates a candidate θ by the following steps:

Estimation Steps

1. Guess 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 $\mathbf{a}$. 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.

[37] The survey measures for willingness-to-pay to improve reliability are fraught with issues such as truthful elicitation, ambiguity of whether costs included back-up generation, heterogeneity across customers and time of day and year, and whether there is advanced notice for the outage so that businesses can plan accordingly. The value we assign here has first order effects on the commitment counterfactual that we run later. To assess robustness to this assumption, we find the lowest possible value of reliability such that allowing the regulator to commit to future rates of return does not induce higher investment. That value is \$25 for a 2.5 percent improvement in reliability. Details are in Section 6.

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 criterion 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 DW-Nominate score of a state into an implied weight on consumer surplus by $\alpha_{it} = a_0 + a_1 d_{it} + a_2 rep_{it}$. 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.

We then invert energy loss into an unbiased estimate of effort according to the model: $\hat{e}_{it} = \frac{Q_{it}}{l_{it}}$. In the estimation algorithm, $\hat{e}_{it}$ is regressed on functions of state variables, and the estimation error due to $\hat{e}_{it}$ being different than e_{it} does not affect the properties of the estimator. An unbiased estimate of effort is as good as observing effort for our purpose.

The next step is to recover an estimate of the auditing intensity. The first order condition of the utility with respect to effort choice implies that $\kappa = 1 - \frac{2\gamma_e e}{Q p_f}$. We use this relationship to derive 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, we can plug in the unbiased estimate of effort to get an unbiased estimate of audit intensity, which, like effort, is as good as observing audit intensity for our purposes. At this point, we are in a standard BBL scenario.

To estimate the policy functions, we 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 estimated Markov process for α, the estimated investment policy function, and the variance of the error term in the investment policy, we simulate 400 paths of length 200 of α and k. For each path, given the candidate model parameters, one can compute the stream of per-period payoffs for both the utility and consumers. The mean net present value across paths is the estimated value of being at a point in the state space. This forward simulation procedure produces estimated value functions for the utility and consumers.

Given the candidate model parameters and the implied simulated value functions, we solve for the optimal policies for each player in each state given the opponent's observed policies. This is the most computationally intensive part of the routine. Given the optimal policies and the Markov process for α, we compute first and second moments of investment, regulated rate of return, and effort.

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 on the state space. We add eight more moments into the criterion function: the mean and the standard deviation of three variables – the rate of return, investment level, and effort – and the regression coefficients of effort and rate of return on fraction of republican commissioners and DW-nominate scores. Explicitly, the criterion is composed of the following components:

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

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 at each point in the state space. The next six components are mean and variances of observables.[38] 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 DW-nominate score and fraction of republican commissioners, and effort on DW-nominate score and fraction of republican commissioners. We set the weighting matrix W to adjust for differences in scaling across moments. We compute standard errors by bootstrap.

[38] As the parameters **a** affect transitions across states, these moments are not implied by matching observed policies to implied optimal policies.

5 Estimation Results

In this section, we interpret the economic magnitude of parameter estimates and discuss the identification of the parameters. Table 7 shows the estimation results.

Table 7: Parameter Estimates

Parameter	Related Model Component	Estimate	Standard Error
$\gamma_e(10^7)$	effort cost	3.6602	0.5055
$\gamma_\kappa(10^{10})$	audit cost	44.4838	6.4058
$\gamma_r(10^{10})$	market return adjustment cost	6.1717	7.8874
$\eta(10^4)$	quadratic investment cost	3.6969	12.5796
$\sigma_i(10^6)$	investment-level-specific error	0.2149	0.0973
a_1	weight on consumer surplus	0.9970	0.0018
a_2	weight on consumer surplus	-0.0033	0.0014
a_3	weight on consumer surplus	-0.0035	0.0011
N	2331		
Criterion	0.5673		

Magnitudes The effort cost parameter implies that decreasing energy loss by 1% at the mean effort would entail a disutility worth about \$230,000 to utility management. This is comparable to the cost of hiring three power system engineers. The adjustment cost for capital, η, implies that increasing capital by 10 percent at the mean would have an additional cost, over and above the cost of the capital itself, of . This parameter is likely picking up heterogeneity across utilities not specified in the model, such as population growth rates and features of the terrain. The regulator's cost parameters imply that decreasing cost pass-through an additional X from Y away from full pass-through bears the same cost as adjusting the rate of return by Z. The mapping from political variables to weight on consumer surplus is of particular interest for this paper. a_1 sets the level of weight on consumer surplus. It is very close to one. This level is sensitive to the choke price that we calibrated. a_2 and a_3 are of similar magnitudes. The fraction of Republican commissioners and the DW-nominate score also have variation of similar magnitudes. Therefore, these two factors contribute to the weight on consumer surplus in similar magnitudes. In our formulation, these two factors are the sole determinants of the weight that regulators place on consumer surplus.

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. The rate of return is decreasing in both dimensions. Investment is also decreasing in both dimensions. Investment is decreasing in the dimension of 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.

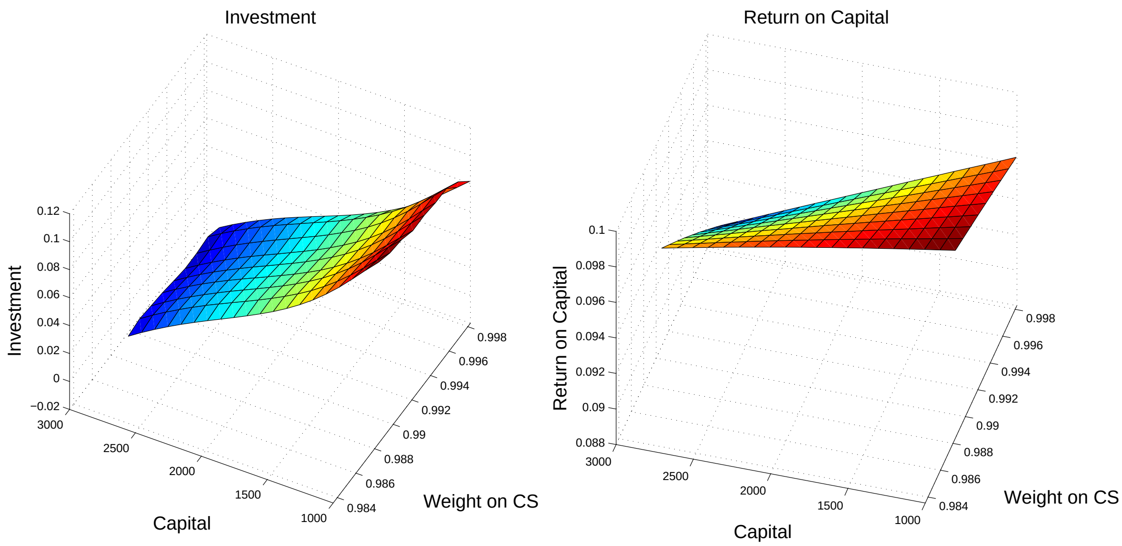

Figure 2: Investment policy of utility and rate of return policy of regulator

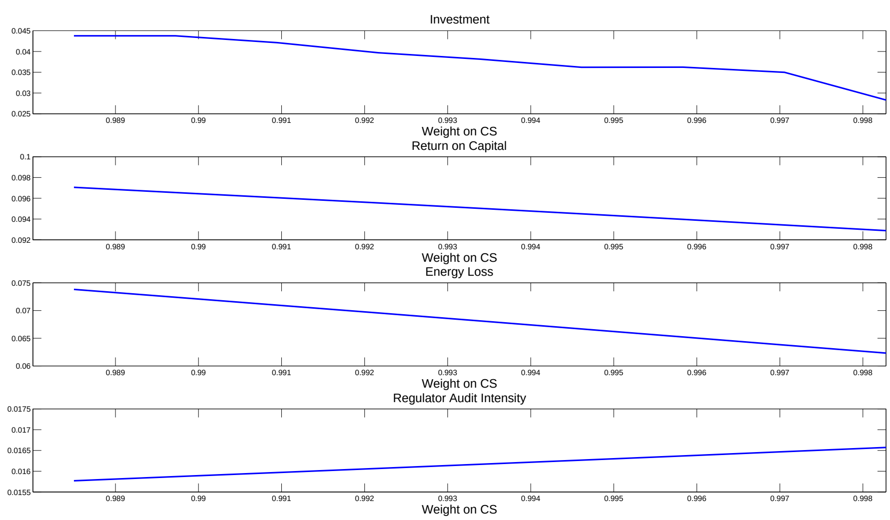

Figure 3: Investment policy of utility and rate of return policy of regulator

Identification Parameter estimates are intuitively linked to specific features of the data. We describe these relationships using the notions of sensitivity and sufficiency from Gentzkow and

Shapiro (2013). The summary statistics we use are the means, variances, and correlations between the primary variables: capital levels, fraction of Republican commissioners, DW-Nominate score, investment, energy loss, and regulated rates of return. We report two tables in Appendix . The first table is the scaled sensitivity measure for each parameter with respect to each of the chosen summary statistics. We computed this by re-estimating the model at different bootstrapped samples of the data. We bootstrapped blocks of all yearly observations for a utility-state pair, estimated the model parameters using the primary estimates as starting values, and regressed the estimates on the summary statistics. The second table corresponds to measuring sensitivity by autonomously manipulating different dimensions of the data, and re-estimating the model. Manipulations included adding or subtracting to all observations on energy loss, investment, and rate of return. We also did manipulations consisting of mean preserving correlated spreads over pairs of variables. We report the raw sensitivity measures for this exercise.

Two results stand out. First, in Table 9, the parameters a_1 and a_2 are very sensitive to the regressions of effort and rate of return on political variables. This is intuitive and provides a direct link between the regression results at the beginning of the paper and the estimates of the non-linear and dynamic behavioral model. In words, we estimate that more conservative regulators place more weight on utility profits than less conservative regulators 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 one observes higher rates of return and more energy loss with more conservative regulators.

Second, the mapping from the simple summary statistics of the data to the other parameters $\gamma_e, \gamma_\kappa, \gamma_r, \eta$, and σ_i is not transparent. Sufficiency statistics are generally low between 0.1 and 0.3. For any given parameter, in both Table 9 and Table B, there are typically numerous summary statistics whose sensitivities are of similar magnitudes. This is not surprising given that the model consists of a fixed point between the fixed points of two Bellman equations, each of which has two continuous control variables. Nonetheless, Table B provides some additional intuition in light of these findings. For example, the parameters γ_e and γ_κ have large sensitivities with respect to mean energy loss. When energy loss is high, the model explains it with low equilibrium effort. Low equilibrium effort can results from effort being costly or auditing being cheaper. η, the quadratic adjustment cost for capital, and γ_r, the regulator's cost of deviating from a benchmark market return, are both sensitivity to the mean level of investment and the mean rate of return in the data. All parameters are sensitive to the dispersions in investment, rate of return, and energy loss.

6 Counterfactual Experiments

We perform three counterfactual experiments: (1) allowing commitment to future rate of return policies by the regulator, (2) minimum auditing requirements for the regulator, and (3) enforcing minority representation on the regulatory commission. The first two are theoretical benchmarks relating to the two fundamental obstacles to efficient regulation: time inconsistency and asymmetric information. The key intuition is that more conservative environments reduce the problem of time inconsistency, while less conservative environments reduce the problem of asymmetric information. The third, enforcing minority representation, is a policy that is in place in some commissions whose goal is to reduce the influence of politics on regulation. We first describe the results of the three counterfactual experiments, summarized in Table 8. Then, we discuss the relative importance of asymmetric information and time inconsistency problems, comparing the first two counterfactual experiments.

6.1 Commitment by Regulator

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, 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 confirm and quantify the importance of this intuition.

In a world where the regulator could credibly commit to future rates of return, the adjudicated rate of return is 43 percent higher than in the baseline. Investment rises by a factor of four. Consumers would pay higher prices and receive service with better reliability. Utility profits are higher and consumer surplus is lower. Total surplus increases by 1.4 percent, with more than all of the benefits accruing to the utility. The main driver of this result is that the possible improvements in reliability from capital additions are cheap compared to the their estimated benefit.[39] The loss in consumer welfare caused by high electricity price resulting from utilities' high rate of return is largely compensated for by improvement in reliability resulting from an increase in investment. The large gain in utility's profit dominates the small loss in consumer welfare, which results in a net increase in total welfare.

The reason in our model that this doesn't occur in reality is 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 prices.

[39]The counterfactual increase in regulated returns and investment are thus highly sensitive to the value that one places on reliability. The measures we employ for the value of reliability described in Section 4.1 are subject to various sources of error. We address this issue in Appendix A.

Table 8: Results of Counterfactual Experiments

		Counterfactual 1		Counterfactual 2		Counterfactual 3	
	Baseline	Commitment	Δ %	Minimum Audit	Δ %	Minority Representation	Δ %
Mean Return on Capital	0.09579	0.13725	**43.29%**	0.09579	0.00%	0.09579	0.00%
SD Return on Capital	0.00156	0.00224	**43.26%**	0.00156	0.01%	0.00147	**-5.73%**
Mean Audit	0.98381	0.98381	0.00%	0.98352	-0.03%	0.98381	0.00%
SD Audit	0.00014	0.00014	-0.03%	0.00010	**-27.50%**	0.00009	**-34.94%**
Mean Investment Rate	0.03440	0.16466	**378.63%**	0.03430	-0.30%	0.03439	-0.03%
SD Investment Rate	0.00680	0.02131	**213.34%**	0.00678	-0.22%	0.00661	**-2.74%**
Mean Energy Loss	0.06775	0.06755	-0.29%	0.06358	**-6.15%**	0.06774	-0.01%
SD Energy Loss	0.00207	0.00199	-3.90%	0.00150	**-27.50%**	0.00134	**-34.94%**
Utility Profit Per Capita	2022.12304	4661.05102	**130.50%**	2021.36405	-0.04%	2021.99605	-0.01%
Consumer Surplus Per Capita	39629.57648	37566.60026	**-5.21%**	39638.14534	0.02%	39629.61994	0.00%
Total Welfare	41651.69952	42227.65127	**1.38%**	41659.50939	-0.02%	41651.61598	-0.01%

Note: This table reports results from counterfactual simulations. The first column corresponds to outcomes at the estimated status quo. The subsequent columns indicate levels and percentage changes of outcomes in counterfactual scenarios relative to the estimated status quo.

Actions that regulators can take in reality for commitment include making side-deals 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.[40] A more drastic action would be government ownership of utilities which is more common in Europe where SAIDI rates also tend to be lower. However, given the multitude of other differences between Europe and the US and other costs and benefits of government ownership, a more careful analysis would be necessary to understand this relationship.

On the whole, combining our results on the relationship between capital and reliability together with surveyed measures on the value of reliability indicates a moderate to large amount of under-investment in electricity distribution infrastructure. We explain this level of under-investment using a model of a regulator who can not commit to future rates of return, which induces the utility to be wary of large investments. We caution that the value of reliability is measured with many sources of error, and therefore the exact magnitude is uncertain. However, for time inconsistency to have zero effect in our model, survey respondents must be over-estimating the value of reliability by a factor of four. We view such a large discrepancy as possible but unlikely. Therefore, we conclude that the fear of regulatory hold-up has likely led to under-investment in electricity distribution capital.[41]

6.2 Auditing Requirement

We now switch focus to the problem of asymmetric information. This manifests itself as energy loss. The policy we consider requires auditing of costs by independent, third-party auditors. Specifically, we consider a uniform implementation of the maximum audit intensity estimated from our data.[42]

On average, energy loss decreases by about six percents (half a percentage point of the total energy distributed). This implies that society could consume the same amount of electricity, saving on the order of 1 billion dollars per year.

[40]The *Energy Infrastructure Modernization Act* 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. Commonwealth Edison praised the act as "[bringing greater stability to the regulatory process to incent investment in grid modernization." (McMahan (2012))

[41]In this study, we abstracted from investments by distribution utilities in new technologies, such as accommodating distributed generation from household solar power. In practice, the large investment predicted by our counterfactual experiments should be broadly interpreted to include investments in new technologies.

[42]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.

6.3 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 a fraction of 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 commissioners can be from the same political party. We simulate such a rule with a *mean-preserving shrinkage* of the Markov process governing the evolution of the regulator's weight on consumer surplus vs. utility profits. 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.[43]

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. Remaining cognizant of the modelling assumptions that enter the analysis, our estimates imply that time inconsistency and under-investment are quantitatively larger problems than asymmetric information and energy loss. The results suggest that jurisdictions where reliability is poor might benefit from appointing more conservative regulators whereas jurisdictions with good reliability but poor energy loss might benefit from appointing more liberal commissioners. In the first case, such a tilting of the regulatory board would help alleviate the time inconsistency problem, though investment would still be less than under full commitment.

7 Conclusion

This paper studies how two fundamental issues in natural monopoly regulation, time inconsistency and asymmetric information, interact with regulators' political ideology, focusing on electricity distribution. We first document that more conservative political environments lead to higher regu-

[43] A more complicated version of our model can also predict a larger influence. We have aggregated many different utilities when estimating the parameters of the utility-regulator model. In particular, the Markov process governing the single index of weight on consumer surplus versus utility profits 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.

lated 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 than consumer surplus, grant higher rates of return which lead to more investment. This behavior is advantageous for society in light of 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.

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A Counterfactual Robustness with respect to Value of Reliability

To be completed

B Sensitivity Tables

These tables correspond to two different takes on sensitivity from Gentzkow and Shapiro (2013).

	γ_e	γ_κ	a_0	a_1	a_2	η	γ_r	σ_i
Mean Investment	-0.068	0.079	0.042	0.015	0.001	0.071	0.113	-0.015
Mean Return	-0.131	0.116	0.011	-0.024	-0.037	-0.154	0.047	0.082
Mean Energy Loss	-0.081	0.021	0.067	-0.038	-0.015	-0.085	0.072	-0.171
Mean Republican Fraction	0.078	-0.023	-0.074	-0.110	0.178	0.048	-0.037	0.217
Mean Nominate	0.062	-0.074	0.010	0.072	-0.152	0.002	0.126	-0.136
SD Investment	-0.034	0.094	0.006	-0.060	0.128	0.059	0.102	0.091
SD Return	-0.002	-0.005	0.112	-0.052	-0.050	-0.038	-0.010	-0.138
SD Energy Loss	-0.126	0.107	0.037	0.061	-0.076	-0.082	0.037	-0.122
SD Republican	0.242	-0.179	-0.098	-0.150	0.094	0.013	-0.084	-0.032
SD Nominate	-0.089	0.049	-0.039	-0.069	0.035	0.018	0.088	0.042
Corr(Energy Loss,Republican)	0.005	-0.037	-0.074	0.344	-0.176	-0.055	-0.112	0.073
Corr(Return,Nominate)	0.128	-0.137	-0.058	0.113	-0.192	0.056	-0.213	0.093
Corr(Return,Investment)	-0.153	0.163	-0.058	0.039	0.056	-0.051	-0.045	0.020
Corr(Capital,Investment)	0.121	-0.095	-0.118	0.237	0.038	0.206	-0.008	0.124
Corr(Capital,Return)	-0.177	0.110	0.060	-0.295	0.054	-0.277	-0.036	0.177
Corr(Capital,Energy Loss)	-0.039	0.008	0.021	0.040	0.037	-0.089	-0.126	-0.066
Corr(Energy Loss,Investment)	-0.031	0.001	-0.042	0.089	-0.019	0.014	-0.042	0.049
Corr(Republican,Investment)	-0.004	-0.007	-0.214	0.019	-0.050	0.121	-0.007	0.041
Corr(Nominate,Investment)	-0.108	0.058	-0.440	0.192	-0.152	0.099	-0.040	0.158
AutoCorr(Republican)	-0.221	0.161	0.012	0.034	-0.057	0.050	0.067	0.086
AutoCorr(Nominate)	0.161	-0.102	0.064	-0.009	-0.019	-0.033	0.008	-0.076
Mean Capital	0.068	-0.034	-0.131	-0.028	0.038	0.030	-0.124	0.073
SD Capital	-0.145	0.123	0.100	0.019	-0.073	-0.120	0.053	-0.051

Table 9: This table presents scaled sensitivity measures obtained by re-estimating the model's parameters on block-bootstrapped datasets, regressing the bootstrap estimates on summary statistics of the bootstrapped data sets, and scaling the regression coefficients by the standard deviation of the summary statistic divided by the standard deviation of the bootstrap estimated parameter.

	γ_e	γ_κ	a_0	a_1	a_2	η	γ_r	σ_i
Mean Investment	5.244	-99.719	0.106	0.063	0.030	-99.264	307.759	-3.541
Mean Return	-0.356	-5.273	-0.069	-0.002	0.024	374.751	-189.122	2.200
Mean Energy Loss	-10.272	58.751	-0.001	0.000	-0.003	-9.767	-147.543	-1.325
Mean Republican Fraction	0.276	-8.233	0.001	0.002	-0.002	2.725	-6.495	0.074
Mean Nominate	0.093	-5.107	0.000	-0.001	-0.002	2.716	-8.084	0.102
SD Investment	10.444	-708.235	-2.411	-0.878	-0.083	-1033.187	211.943	-17.187
SD Return	80.552	-1753.896	-0.168	0.352	-0.035	2204.871	-589.671	33.378
SD Energy Loss	38.777	-587.706	0.690	0.080	0.370	-1792.558	2598.606	10.276
SD Republican	-1.014	22.176	0.000	0.001	0.002	3.759	2.069	-0.084
SD Nominate	-0.088	1.500	0.000	-0.002	0.000	-3.411	-1.829	-0.018
Corr(Energy Loss,Republican)	-1.846	72.358	0.098	0.010	0.046	-23.314	28.888	-0.052
Corr(Return,Nominate)	0.975	-4.844	0.029	0.029	-0.005	183.430	-301.675	4.726
Corr(Return,Investment)	0.057	10.596	0.016	0.010	0.007	0.990	-3.303	0.240
Corr(Capital,Investment)	-4.804	94.480	0.008	-0.004	-0.010	-73.687	-25.704	-0.282
Corr(Capital,Return)	-1.309	25.486	-0.002	-0.008	0.000	-59.382	4.360	0.258
Corr(Capital,Energy Loss)	-1.532	31.546	0.003	-0.002	-0.001	-37.384	6.768	-0.204
Corr(Energy Loss,Investment)	0.783	-22.538	-0.015	-0.001	0.004	51.083	10.532	0.857
Corr(Republican,Investment)	-0.016	-4.718	-0.018	-0.007	-0.005	-0.225	-6.195	-0.427
Corr(Nominate,Investment)	0.223	-12.026	-0.033	0.007	-0.015	-0.958	-14.067	-0.331
AutoCorr(Republican)	-0.518	12.026	0.002	-0.001	0.006	6.701	9.467	0.136
AutoCorr(Nominate)	0.009	-0.539	-0.001	0.000	0.001	1.312	0.310	0.046
Mean Capital	0.000	0.001	0.000	0.000	0.000	-0.002	0.011	0.000
SD Capital	0.001	-0.028	0.000	0.000	0.000	0.041	-0.009	0.000

Table 10: This table presents unscaled sensitivities for autonomously manipulating different variables in the data set, re-estimating the model's parameter on the manipulated data, and linearly regressing those estimates on summary statistics of the manipulated data.