THE EFFECTS OF QUALITY STANDARDS ON ELECTRICITY SERVICE RELIABILITY

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Abstract

As power outages increase in frequency and duration, service reliability has emerged as an important issue in electric utility regulation. This paper primarily seeks to evaluate the effectiveness of quality regulation on service reliability. The empirical analysis considers two standard indexes that measure service reliability: the System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI). Using panel data of 62 U.S. investor-owned electric utilities, from 1998 to 2011, I implement the random effect approach to model outage duration and frequency as a function of quality standards dummy while controlling for utility size, customer density, percent plant underground and retail sales per customer. The results suggest that the presence of quality standards does improve quality of electricity service. To extend the analysis, I introduce interaction terms between quality standards and expenses in the model and examine the causal chain connecting quality standards, cost expenditures, and service reliability. The results suggest that quality standards favorably affect service reliability, especially SAIDI, through increased utility expenditures on operations and maintenance.

1. INTRODUCTION

Power outages are becoming more common in the U.S. In 2008, according to the Eaton Blackout Tracker, there were 2,169 power outages in the U.S. affecting 25 million people. Outages increased to more than 3,000 in 2011, affecting 41.8 million people. Such power disruptions are estimated to drain between $80 billion and $188 billion from the U.S. economy every year due to loss in productivity (Eto and LaCommare, 2004).

Ensuring service reliability has become increasingly important in utility regulation. Concerns over the effect on quality of service rose as incentive regulation replaced traditional rate of return regulatory regime in the late 1980s, to strengthen incentives for cost efficiency and lower the consumers' price. Both theory and empirical evidence indicate that when a regulator imposes revenue or price ceilings that are weakly related to costs, a firm's incentive to deliver efficient levels of service quality are lowered (Ai and Sappington, 2002). A simple price cap or other incentive plan rewards the firm for lowering cost, but cost reductions can also be achieved by shortchanging quality.

The current trend of electric utility restructuring and deregulation also pose a unique challenge for enforcing service reliability. As competitive generation markets and open access is expected to increase the average distance electricity is transported, additional costs and reliability issues might stem from the reduced benefits of coordination, the increase in complexity of the delivery system, scheduling, and other operating procedures (Blumsack et al., 2006). Additionally, facility maintenance is expensive and can be deferred to reduce generation costs. Experts are concerned that without regulatory oversight utilities will focus too much on profits and not enough on electric reliability (NRRI, 2000). These concerns highlight the need to act towards guaranteeing uninterrupted electricity supply.

This paper evaluates the effect of quality standards on service reliability. Regulators enforce quality regulation to improve service reliability. Such a scheme may specify (i) performance standards and (ii) rewards and penalties that closely approximate the marginal benefits and costs to consumers of increases and decreases in quality. A profit-maximizing regulated firm will expand quality to the point where the marginal benefit of additional quality to consumers (and thus the firms marginal reward) equals the firms marginal cost of increasing reliability (Sappington, 2007). This is the desirable, welfare-maximizing level of service quality. Designing an incentive mechanism that will induce firms to deliver the welfare-maximizing levels of quality is, in practice, quite challenging.

A significant number of quality standards with incentive mechanisms have been approved for US utilities, which penalize (and sometimes reward) utilities based on how their measured service reliability performance compares to established benchmarks. A 2007 report found twenty states had plans in which utilities might be penalized or (much less frequently, rewarded) for performance differences relative to established standards (PEG 2007). Given the growing trend of power outages, it remains to be seen these standards have been truly effective.

This paper empirically examines the impact of quality standards on service reliability while controlling for operational characteristics, such as utility's size, customer density and plant undergrounding, which may affect quality of service.[1] The empirical analysis uses two standard indexes that measure service reliability: the System Average Interruption Duration Index (SAIDI) and System Average Frequency Duration Index (SAIFI). Using panel data of 62 U.S. investor-owned electric utilities, from 1998 to 2011, I implement the random effect approach to model outage duration and frequency as a function of quality standards while controlling for

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[1] This work focuses on quality standards that outline provisions for penalties and rewards.

other operational characteristics.[2] This exploration is important because, to date, there is no empirical evidence on the relationship between quality standards and service reliability in the U.S. electricity industry.

The results from the random effect model suggest that the presence of quality standards does improve quality of electricity service. Furthermore, the analysis also highlights that undergrounding of power lines and an increase in customer density favorably affects service quality.

Additionally, the paper also investigates the channels through which quality standards can affect service reliability, in particular, operations and maintenance expenses of electric utilities. I model these expenses, separately, as a function of the quality standard dummy and control for other explanatory variables. The results indicate that utilities with quality standards have higher expenses per customer. Subsequently, I investigate how changes in these expenses affect reliability by regressing SAIDI and SAIFI against interactions between quality standards and expenses variables. The evidence suggests that quality standards favorably affect service reliability, especially outage duration, through a causal chain involving increased utility expenditures on operations and maintenance activities.

The rest of this paper is organized as follows: Section 2 discusses the measures of service reliability for the investor owned utilities and data complications. Section 3 explains the empirical model and control variables used for this study. Section 4 presents parameter estimates for the model to study the impact of quality standards on the duration and frequency of electric outages. Section 5 extends the empirical analysis by investigating the relationship between quality standards, operations and maintenance expenses, and quality of service. Section 6 provides a brief summary of the main findings and discusses future extensions.

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[2] Availability of comparable reliability metrics limited the number of utilities used in the study.

2. MEASURING RELIABILITY OF SERVICE

Power outages are the principal concern of electric service reliability. This paper utilizes the System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI), which measure the duration and frequency of power outages. These two metrics are commonly used by utilities and industry experts when reporting on the consistency of electricity service to customers.

These metrics are computed using the total number of customer interruptions, the duration of these interruptions measured in minutes, and the number of consumers the utility serves in a given year. According to IEEE Standard 1366 (1996), the metrics are calculated as follows:

$$\text{SAIDI} = \frac{Total\ \ Customer\ Interruption\ Minutes}{Total\ Number\ of\ Customers\ Served}$$

$$\text{SAIFI} = \frac{\text{Total Number of Customer Interruptions}}{Total\ Number\ of\ Customers\ Served}$$

SAIDI captures the duration of power interruption per customer for a utility in a given year. Likewise, SAIFI captures the frequency of interruptions per customer for a utility in a given year. Larger values of SAIDI and SAIFI indicate less reliable electricity service meaning that customers, on average, experience longer or more frequent interruptions.[3] Lower SAIDI and SAIFI values represent a better continuity of electricity service to customers.

While SAIDI and SAIFI are widely recognized metrics, there are differences among utilities in the ways they define and measure interruptions. For example, most utilities define an interruption as a loss of service for at least 5 minutes. A few use a 1 or 2 minutes as the criterion.

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[3] In general, power interruption can be caused by either external or internal factors. Utilities can directly control for internal factors, such as the equipment and labor procurement and efficiency of maintenance practices. In contrast, utilities lack control over external factors like climate and topographical characteristics of the service territory. However, it should be noted, that the utility could mitigate them through internal factors. For example, a utility can adopt maintenance practices to be better prepared for ice storms if they are relatively common in the region, or conduct tree trimming programs to curb vegetation related outages.

In addition, the majority of utilities compute SAIDI and SAIFI by excluding outages due to major storms or other weather-related events, but some utilities report these metrics after accounting for major weather events.[4] In order to maintain comparability of reliability metrics across utilities, considerable effort was made to reconcile these aforementioned differences in the data. I use only those data that meet the IEEE standard 1366, which includes outage data that applied the 5 minute criteria and excluded major weather events.[5]

Data on SAIDI and SAIFI were collected either by directly contacting the utilities and state public utility commissions or retrieved from their respective websites. Since different states collected and retained data for varying numbers of years, the result is an unbalanced panel with 684 observations from 62 investor-owned utilities across 19 states, from 1998 to 2011. Figure 1 shows, annually, the number of utilities whose reported reliability data was collected. The figure shows a general increase from 1998 to 2003 in the number of utilities that had quality standards. Twenty-one utilities in the sample had quality standards by 2011, compared to forty-one utilities without standards.

As shown in Table 1, a simple unadjusted comparison of the magnitudes of the SAIDI and SAIFI indices across all utilities and years suggests some interesting differences. The mean interruption duration for utilities with quality standards was 107.58 minutes per year, while for those utilities without quality standard plans, SAIDI averaged 143.61 minutes per year. The T-test result shows that these mean interruption durations, for utilities with and without quality standards, are statistically different at 1% significance level. This suggests that utilities without

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[4] Including major weather events would degrade comparability of the metrics across utilities because (territories served by) utilities differ in terms of intensity and frequency of major weather events (eg. storms) they face.

[5] The standard subscribes a 5-minute criteria for interruption and defines interruptions as “major events” when they are 2.5 standard deviations from the normal day interruption.

quality standards experience longer outages. Additionally, these utilities also experienced greater variation in the SAIDI as noted by the larger standard deviation.

Similarly, there is a substantial difference in average frequency of interruptions between those with and without quality standards. SAIFI averages 0.96 interruptions per year for utilities with quality standards versus 1.43 interruptions per year for those without. These are statistically different at the 5% significance level, suggesting that utilities without quality standards experience higher frequency of interruptions. Furthermore, the standard deviations and ranges (max - min) shows that reliability metrics for the utilities that have quality standard are clustered closer around the mean compared to other utilities that do not have quality standard.

While these preliminary analyses suggest quality standard improves service reliability; other factors such as number of customer, customer density and undergrounding affect reliability too. We next turn to a systematic examination of the underlying causal relationships, controlling for these factors.

3. EMPIRICAL MODEL

Previous studies have sought to model service reliability in the electricity sector. In doing so, these empirical studies have analyzed how certain utility characteristics affect reliability of service. For example, Fumagalli et al. (2007) studied the effect of privatization and managerial changes on SAIDI for 31 Italian power distributors, using a fixed effect approach and panel data from 1998 to 2004. Besides using variables capturing ownership and governance structures, the number of customers was included as an additional variable. More recently, using a translog function, Fenrick and Getachew (2012) modeled SAIDI and SAIFI against the number of customers, customer density, percentage plant underground and percentage service territory forested. The dataset included observations from 76 U.S. investor-owned utilities covering the years 1998 to 2010.

Reichl et al. (2008) provided very comprehensive models of reliability featuring SAIDI and SAIFI for the Austrian power distribution sector. Using unbalanced panel data with 43 observations from 12 distributors for the years 2002-05, the authors explored the effect of population density, grid length, percent plant underground, and lagged values of grid tariff (as a proxy for incentive regulation) on service quality.[6] They found that undergrounding and density have favorable and statistically significant effects on both interruption duration and frequency.

The empirical models in this paper is similar to the one used by Reichl et al. (2008). Outage duration and frequency metrics, which serve as proxies for service reliability, are the dependant variables. These measures are regressed on a number of explanatory variables capturing utility-specific characteristics. Additionally, for the purpose of this study, a new variable is included in the model to capture the presence or absence of explicit quality standards. The basic model takes the following form:

$$\mathbf{quality_{it} = \alpha_0 + \delta QS_{it} + \beta Y_{it} + Trend_{it}} + \varepsilon_{it}\ , \qquad \boldsymbol{\varepsilon_{it} = u_i + w_{it}} \qquad (1)$$

where quality_{it} is the natural log of the reliability metric (SAIDI or SAIFI) for utility i in year t. QS_{it} is a dummy variable that captures the absence or presence of quality standards. A variable Trend_{it}[7] is included in the model to capture time trend. $\boldsymbol{\varepsilon_{it}}$ is the error term composed by utility-specific error (u_i), which allows to control for unobserved utility characteristics, and the disturbance term (w_{it}). Y_{it} is a vector of other explanatory variables that capture operational characteristics of the utilities.

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[6] Incentive regulation is expected to restrain tariff increases.

[7] The time trend, TRENDit, enters as a linear time variable.

A review of previous related empirical works aided the process of selecting appropriate explanatory variables that capture utility specific characteristics and affect service reliability. The study uses the following explanatory variables:

The focus of this study is to investigate the relationship between service reliability and quality standards. Therefore, the primary explanatory variable of interest is the quality standard dummy QS_{it}. It takes the value of 1 if quality standards are explicitly incorporated in the regulation mechanism for utility i in year t, such that the utility is penalized for underperformance or rewarded for meeting the benchmarks.

Additionally, several variables that account for specific characteristics of electric utilities, denoted by the vector Y_{it}, are included in the model. The first such variable is $NCUSTOMER_{it}$. It denotes the total number of retail customers[8] for utility i in year t, and serves as proxy for the size of the utility. Utilities serving fewer customers are expected to be at a disadvantage relative to larger utilities that have more customers to spread system-wide reliability initiatives across (Fenrick and Getachew, 2012). Table 2 shows the summary statistics for $NCUSTOMER_{it}$ and other explanatory variables used in the empirical analysis. Given the minimum and maximum number of retail customers in the sample, ranging from just over 10,000 to over 5.2 million, and a standard deviation of 1.1 million compared to a mean of 800,000; we can say there is high variability in the sample in terms of utility size.

Additionally, $DENSITY_{it}$ captures the number of customers per mile of distribution lines for utility i in year t. This variable controls for rural versus urban areas which differ both in the number of people impacted by any event as well as in the time likely required for the utility to find and correct any problem. Thus, the coefficient on this variable is expected to be negative. The maximum and minimum customer density of about 150 and 17 customers per mile,

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[8] To reduce decimal points in the coefficient estimate the numbers of customer has been divided by 100,000 for regressions.

respectively, shows that the sample set accounts for utilities that serve both rural and highly dense urban areas. Since standard deviation for customer density is much smaller than the mean, we can deduce that data on customer density is clustered around the mean.

$UNDERGR_{it}$ denotes the percentage of the power lines and conduits that are underground for utility i in year t. The prevalence of system undergrounding has a conflicting effect on overall service reliability. Relative to above-ground wires, underground lines are less influenced by environmental factors. The downside of undergrounding power lines, however, is that when outages do occur it may take utility crews longer to locate the cause of the outage and to restore power. Thus, there are two effects working in opposite directions regarding the duration of outages, making a priori expectation impossible (Fenrick at Getachew, 2012). Data on undergrounding for the sample utilities varies from a minimum of just over 2 percent to a maximum of 52 percent. On average approximately 21 percent of the utilities' power lines and conduits are underground. The data on undergrounding experiences little variation from the mean, as noted by the lower standard deviation.

Finally, $SALES_{it}$ refers to total retail sales in megawatt-hour (Mwh) per customer for utility i in year t. This variable serves as a proxy for economic environment. The minimum retail sales of roughly 4 Mwh per customer is obviously associated with a utility that largely serves residential customers and less volume of economic activity. On the other hand, the maximum retail sales of 115 Mwh per customer are from a utility that serves a territory with more economic activity, due to higher propensity of commercial customers. The data on retail sales averages at around 23 Mwh per customer across the sample utilities and there is little variation from this mean.

The data on the explanatory variables used in the econometric model are gathered from publicly available sources. Information on quality regulation for the utilities was collected by reviewing regulatory orders from various state public utility commissions' websites. Data on the number of retail customers, distribution miles and sales volume were gathered from EIA-861 forms retrieved from the Energy Information Administration website. The percentages of plant underground were gathered from FERC Form 1 data submitted on an annual basis by each company. As mentioned previously in section 2, lack of availability of SAIDI and SAIFI data for all the year has limited the study to use unbalanced panel for 62 IOUs from 1998 to 2011.

I implemented the random effects approach, to estimate the basic model. It was deemed reasonable because the variables in the model change slowly over time. The value for quality standard dummy, customer density and percent plant underground, for a given utility, change very little over time. If variables change little, or not at all, across time, a fixed effects model may not work very well or even at all. There needs to be within-subject variability in the variables if we are to use subjects as their own controls. If there is little variability within regressors then the standard errors from fixed effects models may be large, which reduces possible significance. Conversely, random effects models will often have smaller standard errors.

Additionally, to determine whether the fixed or random effects approach was more appropriate for model (1), the Hausman (1978) specification test was applied. The Hausman test examines whether, under the null hypothesis, the utility-specific and time-specific effects are uncorrelated with the other regressors in the model. If the null hypothesis is not rejected, both the random effects and the fixed effects models are consistent, but only the random effects model is efficient.[9] The Hausman test did not reject the null hypothesis of random effects. It was therefore concluded that random effects model with GLS estimation was consistent and more efficient than the fixed effects version. The next section presents the results for model (1).

4. ESTIMATION RESULTS

Table 3 presents the coefficients for explanatory variables for the estimation of average duration of electric outages and average frequency of electric outages. Overall the regression result supports the hypothesis that prescribing quality standards improves service reliability. The result shows that adopting quality standards regulation has decreased outage duration by a little less than 4 percent. The estimated coefficient for the quality standards dummy in the SAIFI model is statistically insignificant, but has the expected sign.

The estimated coefficients for total number of retail customers in both models have the expected sign but are insignificant. The negative value means that service reliability improved as utility size increases. This finding is in contrast with the conclusion made by Fumagalli et al. (2007) based on their study of Italian power distributors. Their result showed that an increase in number of customers had statistically significant and adverse effect on outage duration.[10] Fenrick and Getachew (2012) found that an increase in utility size had favorable and statistically significant effect on outage frequency but not on outage duration.[11] Thus, the impact of the number of customers on power outages is mixed.

Higher customer density within service territory, as measured by the number of retail customers divided by total distribution mile, is expected to lower SAIDI and SAIFI values as fewer line miles would be susceptible to outages per customer served. The estimation results

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[9] This means that fixed and random effects models will have the same expected values, but the random effects model will have much smaller standard errors. Using a fixed effects model when the random effects model is consistent may lead to an erroneous interpretation of the statistical significance of coefficients Greene (2008).

[10] Fumagalli et. al. (2007) did not model outage frequency.

[11] Fenrick and Getachew dropped the utility size variable from their estimation results so the sign of the coefficient in unknown for SAIDI model.

corroborate the hypothesis. The findings were significant at a 5% and 1% significance level for the SAIDI and the SAIFI model respectively. Reichl et al. (2008) and Fenrick and Getachew (2012) also concluded that increase in density favorably affected service reliability. The magnitude of the favorable effect is substantially higher, compared to the results in the current work, possibly due to the different estimation methods.

Previous empirical research has found that more undergrounding improves reliability and to be statistically significant. This result is replicated here. A percent increase in plant undergrounding would reduce outage duration and frequency by approximately 5.4% and 2.4%, respectively. The magnitude, in this study, of the effect is slightly larger compared to that in Reichl et al. (2008) and Fenrick and Getachew (2012).

The time trend for both SAIDI and SAIFI is statistically significant. The natural interpretation is that outage duration and frequency are increasing at slightly more than 2% and nearly 1.7% annually. However, a positive value for this parameter estimate may not necessarily mean that reliability is deteriorating over time, but that another unobserved factor may be increasing with time that decreases the quality of service.[12]

5. QUALITY REGULATION AND COST STRUCTURE OF UTILITIES

Quality regulation might be improved if we could determine the channels through which these regulatory instruments affect quality of service. In this final exercise the relationship between quality standards and service reliability is separated into two relationships: 1) the effect of quality standards on cost expenditures of the utility, and 2) the effect of cost expenditures and on SAIDI and SAIFI. The expenditures I consider are operations expenses (OPEX) and

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[12] For example, outage recording has evolved, in more recent years, as computer systems have automated reporting and made it more accurate.

maintenance expenses (MNEX).[13] Operations expenses cover current utility operations, while maintenance involves servicing the infrastructure. Their summary statistics are also presented in Table 2, with the average utility spending around \$703 per customer on operating expenses and \$206 per customer on maintenance expenses.

The following models of expenditures are examined to formally test how quality standards affect O&M expenses of the utility:

$$\text{opex}_{it} = \alpha + \beta_1 QS_{it} + \beta_2 X_{it} + \varepsilon_{it} \tag{2a}$$

$$\text{mnex}_{it} = \alpha + \delta_1 QS_{it} + \delta_2 X_{it} + \varepsilon_{it} \tag{2b}$$

where opex_{it} and mnex_{it} are the natural log of operation expenditures and maintenance expenditures per customer for utility i in year t. These expenditures are regressed against the quality standard dummy QS_{it}, and a vector X_{it} involving external factors that influence expenditures.[14] Operations and maintenance expenditures are examined separately to allow for the possibility that quality regulation affects them differently, and in turn that they affect quality differently.

I then extend the basic model such that it becomes:

$$\begin{aligned}\text{quality}_{it} = \alpha + \gamma_1\, QS_{it} + \gamma_2 OPEX_{it} + \gamma_3 MNEX_{it} + \gamma_4 QS{*}OPEX_{it} \\ + \gamma_5 QS{*}MNEXit + \gamma_6 Y_{it} + \varepsilon_{it} \qquad (3)\end{aligned}$$

Outage duration and frequency are estimated as a function of quality standard dummy, operations and maintenance expenses per customer, interaction terms between quality standard dummy and the two expenses, while controlling for a vector of other explanatory variables Y, as used in model (1). The inclusion of the interaction terms allows us to investigate the marginal effect of any change in operation and maintenance expenses on outage duration and frequency,

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[13] Data on operation and maintenance expenses were collected from FERC form 1 database.

[14] Vector X contains the same explanatory variables as in model (1).

both in the absence and presence of quality standards for utilities. Rewriting the model, as shown below, can make these inferences clearer:

$$\text{quality}_{it} = \alpha + \gamma_1 QS_{it} + (\gamma_2 + \gamma_4 QS)*OPEX_{it} + (\gamma_3 + \gamma_5 QS)*MNEX_{it} + + \gamma_6 Y_{it} + \varepsilon_{it}$$

where the marginal effect on quality due to changes in $OPEX_{it}$ or $MNEX_{it}$ equals to γ_2 or γ_3, respectively, for utilities without quality standards (such that QS = 0). While, for utilities with quality standards (QS = 1), the marginal effects of changes in OPEXit or $MNEX_{it}$ on quality equals $(\gamma_2 + \gamma_4)$ or $(\gamma_3$ or $\gamma_5)$, respectively.

Table 4 reports the estimated parameters for model (2a) and (2b). The results show that quality standard is associated with higher expenses per customer for both, operations and maintenance expenses. For the utilities with quality standards the operations expenses are just under 22 percent higher and maintenance expenses over 7 percent higher. The estimated coefficients for total number of retail customers in both models have negative signs, but are insignificant. The negative value suggests that operation and maintenance expense per customer decreases as utility size increases, implying economies of scale.

The other statistically significant variable that increases both operation and maintenance expenses is USAGE (megawatt hour sales per customer). This could mean that there is a higher cost associated with providing higher service reliability to larger customers. Furthermore, the time trend shows that the operations and maintenance expenses are on average increasing at 6% and nearly 3% annually. Most interestingly, the results show that undergrounding while decreases maintenance cost seems to increase operating expenses. A percent increase in undergrounding leads to approximately 1% increase in operating expenses per customer.

Table 5 reports the parameter estimates for model (3), which examines the more technical relationship between expenditures on operations and maintenance activities, and the duration and frequency of outages. We will first consider the SAIDI model. The coefficients for both operating expenses (OPEX) and maintenance expenses (MNEX) per customer have negative values, but only the latter is statistically significant. We can infer that the marginal effect of an increase in maintenance expenses per customer on SAIDI is -0.5 percent for utilities without quality standards. Thus, a dollar increase in maintenance expenses per customer lowers outage duration by 0.5%. This marginal effect is larger for utilities with quality standards, as shown by the negative and statistically significant coefficient for the interaction term QS*OPEX. Given the value of the coefficient, we can infer that a dollar increase in maintenance expenses per customer improves outage duration by (0.5% + 0.8%) = 1.3%. Additionally, the coefficient for the interaction terms between quality standard and operating expenses (QS*OPEX) is also negative and significant. This means that an increase in the operating expenses per customer has a favorable marginal effect on SAIDI for utilities with quality standards. Given the estimate on result, outage duration improves by 0.6% per additional dollar of operating expenses per customer.

For the SAIFI model, the coefficients of the expense variables are insubstantial in magnitude and insignificant, which limits us from making any statistical inferences. The only variable of interest that is statistically significant is the interaction term between quality standard dummy and maintenance expenses per customer. Given the negative value of the coefficient, we can construe that an increase in maintenance expenses per customer has a favorable marginal effect on outage frequency for utilities with quality standards.

There seems to be a causal relationship between quality standards and improvement in reliability, through increased expenditure. The results for model (2a) and (2b) showed that utilities with quality standards had higher operating and maintenance expenses. Subsequently, the results from model (3) help us infer how these higher expenses affect reliability of service for the regulated utilities. In particular, higher operation and maintenance expense seem to significantly improve outage duration.

6. CONCLUSION

The primary objective of the paper was to examine how implementing quality standards affected electric service reliability, specifically, average outage duration (SAIDI) and frequency (SAIFI), Using unbalanced panel data of 62 U.S. investor-owned electric utilities, from 1998 to 2011, I modeled SAIDI and SAIFI as a function of quality standards while controlling for other operational characteristics such as utility's size, customer density, plant undergrounding and retails sales per customer. Based on the Hausman test, the random effect approach with GLS method was applied to estimate the model.

The findings show that undergrounding and increase in customer density favorably affect outage duration and frequency, which support previous empirical work by Reichl et. al. (2008) and Fenrick and Getachew (2012). Additionally, the presence of quality standards (with associated benefits and rewards) improves the reliability of service.

A second analysis, to evaluate the channels through which quality standards affect reliability, was carried out. This involved modeling the relationship between quality standards and utilities' expenditures, and that between expenditures and outage metrics. Interaction terms between quality standards and expenditures were introduced in the latter model. This helped in capturing the marginal effect of any change in expenses on SAIDI and SAIFI, separately, for utilities with and without quality standards. It appears that quality regulation favorably affects reliability, especially outage duration, through its impact on composition and size of operations and maintenance expenses.

Furthermore, this study finds that there has been a modest, yet statistically significant secular trend of decreasing or declining reported reliability over the years. In making this finding, the directions for next steps in this line of inquiry is outlined; to focus on potential causal factors that would help explain the trend that was observed. Furthermore, it is extremely appropriate to continue exploring differences among utilities to better understand the sources or causes of the secular trends in reliability that we observe. Some of the factors that should be considered include disaggregate measures of weather variability (e.g., lightning strikes and severe storms), utility characteristics (e.g., the number of rural versus urban customers, and utility spending on transmission and distribution maintenance and upgrades, including advanced (“smart grid”) technologies.

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Figure 1: Number of Utilities with SAIDI and SAIFI Data

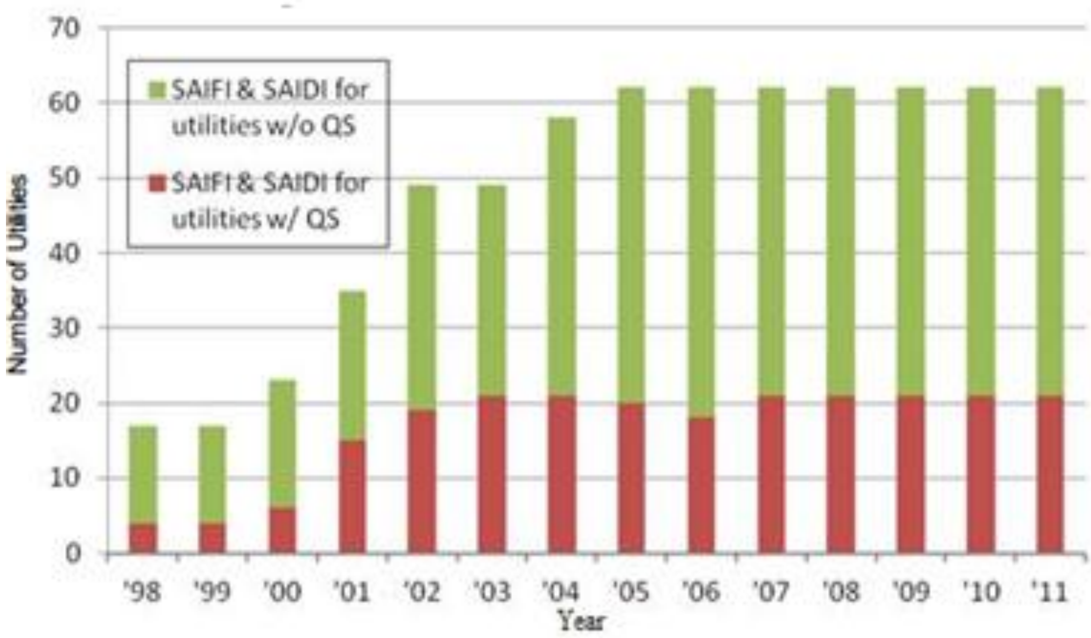

Table 1: Summary statistics of SAIDI and SAIFI

	SAIDI				SAIFI			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
All Utilities	125.39	69.05	17.47	472.39	1.21	0.51	0.08	4.23
with QS	107.58	51.99	23.41	349.81	0.96	0.32	0.08	3.39
without QS	143.61	68.81	17.47	472.39	1.39	0.57	0.23	4.23
T-test Ho: $\mu_{withQS} = \mu_{withoutQS}$ Ha: $\mu_{withQS} - \mu_{withoutQS} < 0$	**p value** = 0.002, t(586.72) = 2.92				**p value** = 0.012, t(552.37) = 1.83			

Note: Value in ( ) denotes the degree of freedom

Table 2: Summary Statistics of Study Variables

Variables	Units	Mean	Std. Dev	Min	Max
SAIDI	Index	125.39	69.05	17.47	472.39
SAIFI	Index	1.21	0.51	0.08	4.23
NCUSTOMER	Number	834685	1129656	10487	5279323
DENSITY	Ratio	43.94	23.05	16.74	150.09
UNDERGR	Percent	20.92	10.73	2.34	52.31
USAGE	Mwh/NCUST	22.94	10.94	3.92	114.59
OPEX	$/NCUST	703.21	967.85	158.92	2673.81
MNEX	$/NCUST	205.92	312.48	12.87	832.37

Table 3: Effect of Quality Standard on SAIDI and SAIFI

Explanatory Variable	**Dependant Variables** **ln (SAIDI)**	 **ln (SAIFI)**
CONSTATNT	4.732***	0.545***
	(0.293)	(0.187)
QS	-0.039*	-0.074
	(0.014)	(0.061)
NCUSTOMER	-0.008	-0.004
	(0.005)	(0.005)
DENSITY	-0.004**	-0.008***
	(0.002)	(0.003)
UNDERGR	-0.054***	-0.024***
	(0.012)	(0.008)
USAGE	-0.003	-0.001
	(0.003)	(0.002)
Trend	-0.021***	0.017***
	(0.003)	(0.004)
R-bar Squared	0.632	0.329
N	684	684

Note: values in parenthesis are robust heteroskedastic standard errors
* = 10%, ** = 5%, *** = 1% significance level

Table 4: Effect of Quality Standard on OPEX and MNEX

Explanatory Variable	**Dependant Variables**	
	ln(OPEX)	**ln(MNEX)**
CONSTATNT	3.068***	1.124***
	(0.190)	(0.012)
QS	0.219***	0.075**
	(0.669)	(0.043)
NCUSTOMER	-0.0002	-0.0001
	(0.0007)	(0.0001)
DENSITY	0.023***	- 0.031
	(0.009)	(0.027)
UNDERGR	0.009	- 0.001
	(0.006)	(0.001)
USAGE	0.013***	0.018***
	(0.004)	(0.007)
Trend	0.062***	0.027***
	(0.006)	(0.003)
R-bar Squared	0.517	0.473
N	684	684

Note: values in parenthesis are robust heteroskedastic standard errors
* = 10%, ** = 5%, *** = 1% significance level

Table 5: Effect of OPEX and MNEX on SAIDI and SAIFI

Explanatory Variable	Dependant Variables	
	ln(SAIDI)	ln(SAIFI)
CONSTATNT	2.439***	0.376**
	(0.345)	(0.169)
QS	-0.009*	-0.005
	(0.004)	(0.003)
OPEX	-0.002	0.000
	(0.004)	(0.001)
MNEX	-0.005**	-0.001
	(0.003)	(0.001)
QS*OPEX	-0.006*	0.000
	(0.004)	(0.000)
QS*MNEX	-0.008**	-0.001*
	(0.005)	(0.000)
NCUSTOMER	0.031	0.000
	(0.027)	(0.002)
DENSITY	0.002	0.000
	(0.008)	(0.000)
UNDERGR	-0.012**	-0.004**
	(0.005)	(0.002)
USAGE	-0.019	0.003
	(0.007)	(0.003)
R- bar Squared	0.498	0.626
N	684	684

Note: values in parenthesis are robust heteroskedastic standard errors
* = 10%, ** = 5%, *** = 1% significance level