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The Impact of Services Quality on Electricity Theft Reduction: An Empirical Analysis of Electricity Distribution Utilities in Pakistan

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Abstract: This study investigates the socioeconomic, administrative, and service quality determinants of electricity theft in Pakistan. The effect of service quality standards on electricity theft is estimated using panel data from eight electricity distribution utilities from 2006 to 2018. The results of utilizing the One-step system Generalized Method of Moments estimator confirm the statistically significant impact of social, administrative, and service quality variables on the illegal use of electricity. Based on the findings, Pakistan's National Electric Power Regulatory Authority is advised to take measures to improve the quality of services. In contrast, the nation's Central Power Purchasing Agency is advised to improve administrative structure by separating retail function from distribution by electric distribution.

Keywords: Electricity theft; Distribution utilities; Service quality; Pakistan.

JEL Classification: C33, O14.

Acknowledgments: We acknowledge that the findings of this study have not been published anywhere else. These are the results of the authors' original research based on the theoretical model and empirical methodology explained in the subsequent chapters of this research.

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1. Introduction

Electricity theft has become a challenge for developed and developing countries, as it causes deterioration to the financial portfolio of electricity distribution utilities (Yurtseven, 2015; Jamil, 2014). Though strict penalties have been implemented to manage this problem, electricity theft continues to negatively impact electricity distribution utilities' financial and administrative position (Yakubu et al., 2018). Electricity theft curtails the investment opportunities of distribution utilities and restricts their ability to initiate capacity development projects (Jamil, 2013). This has become a serious issue in Pakistan, leading to large financial losses and poor quality of services (Ali et al., 2018). Distribution utilities in Pakistan are state-owned monopolies and depend heavily upon government subsidies and public investment to carry out their operations. The financial condition of distribution utilities is vulnerable, as the revenues they collect from the sale of electricity can fall short of their costs, further delaying payments to electricity generation companies. Excessive transmission and distribution losses of distribution utilities adversely affect their profitability and, consequently, the quality of their services (Jamil, 2018).

Transmission and distribution losses are divided into technical and non-technical (Gümüşdere, 2004). Technical losses refer to the physical losses that can occur when electricity passes through transformers, whereas non-technical losses or administrative losses include electricity theft and the effects of electricity theft on the operating cost of distribution utilities (Xavier et al., 2015; Jamil & Ahmad, 2014; Corton et al., 2016). Technical losses are system-related problems, and engineers can settle these losses with proper maintenance and system up-gradation. These losses are inevitable and can be reduced but can never be eliminated. Contrary to this, electricity theft is a social problem that must be addressed through appropriate policies (Gümüşdere, 2004).

There are four types of electricity theft: fraud, stealing, billing irregularities, and unpaid bills (Smith, 2004). Fraud involves meter tampering, in which customers alter meter readings to show that less electricity has been consumed. Fraud is riskier, but in various countries it has been shown that employees in the distribution utilities have been reported to tamper with meter readings. Stealing, also known as illegal hookups, occurs when customers directly connect to an electrical line that is part of the overall grid system to draw power (Smith, 2004). Billing irregularities occur when consumers pay less than their actual electricity consumption because employees are bribed to record less electricity consumed on the meters. Unpaid bills refer to the refusal of customers to pay electricity bills, which is common in poor economic groups. Unpaid bills are associated with revenue collection as they adversely affect the financial position of distribution utilities. Distribution utilities can attempt to control this type of theft by disconnecting those customers who are stealing electricity, but doing so runs the risk of encouraging other types of electricity fraud (Steadman, 2009).

The existing literature on distribution losses has focused primarily on engineering perspectives and has examined the relevance of different techniques to detect electricity theft (Depuru et al., 2011; Ghajar & Khalife, 2003). Similarly, the focus has primarily been on attempts to reduce electricity theft via special devices, different detective methods, and engineering techniques. However, to design a practical policy framework to address this sensitive matter, it is essential to identify the social, economic, and quality-related drivers of illegal electricity consumption (Mirza & Waleed, 2016). A significant portion of system losses come from electricity theft, which is illegal electricity consumption. Therefore, there is a need to prevent electricity theft through a behavioral change in the form of positive reinforcement (socioeconomic incentives), service quality parameters (system reliability, detection, and monitoring system), and penalization (detection bills, fines, and imprisonment). Therefore, this paper uses a comprehensive approach to study the drivers of illegal electricity consumption by incorporating socio-economic and quality of services factors in the standard theft model.

1.1 Contribution of the Study

This study aims to examine the determinants of electricity theft in Pakistan. Extensive empirical work is available on the economics of crime, but very few studies have examined the phenomenon of electricity theft (Smith, 2004; Estache et al., 2006; Dal B6 et al., 2007; Gulati & Rao, 2007; Nakano & Managi, 2008 & Nagayama, 2010). In the case of Pakistan, literature on this issue is even more sparse: Jamil & Ahmad (2014) is the pioneering empirical work in this regard, which examined the determinants of electricity theft in Pakistan, including the role of quality measured through load shedding. Mirza & Hashmi (2015) used time series data to analyze the macroeconomic factors affecting electricity theft in Pakistan. More recently, Jamil & Ahmad (2019) developed a principal-agent-client model to examine the behavior of consumers regarding the theft of electricity. However, these studies analyze the socio-economic factors of electricity theft and do not often consider the role of service quality standards.[1]

The electricity market in Pakistan experienced reforms in the late 1990s, with the power sector broken down into generation, transmission, and distribution segments (Saleem, 2007). The distribution utilities perform the electricity retailing function. After reforms, the National Electric Power Regulatory Authority (NEPRA) was established to govern the electricity market operations. The electricity generation sector was opened for private investment, while transmission and distribution networks were still under the control of the government (Mirza et al., 2017). The electricity distribution network in Pakistan comprises ten distribution utilities, including GEPCO, PEPCO, IESCO, LESCO, FESCO, MEPCO, HESCO, QESCO, SEPCO, and TESCO. Distribution utilities in Pakistan are state-owned monopolies subject to rate of return regulation (Mirza & Mushtaq, 2022). Under the Rate of Return (ROR) regime, tariff rates are determined by considering their costs and distribution margin, and tariff petitions are submitted to NEPRA for public hearing (Ashraf & Khan, 2016; Mirza et al., 2021). Finally, NEPRA determines the tariff rates after conducting a public hearing on these petitions.

The tariff rates determined after the hearing remain in force until the new hearing is called. In contrast, NEPRA and customers can request a petition hearing when they believe the tariff is higher than the allowed rate of return. Under the ROR regulatory framework, NEPRA limits utility companies' profits. Further, rate-of-return regulations do not encourage efficiency as this approach does not provide incentives for capital investment and improved quality of services. Although reforms in the electricity market were introduced in the 1990s, quality guidelines to

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[1] Service quality refers to the reliable and continuous supply of electricity (Engineroom, 2012). A distribution network operating with improved service quality ensures the reliable provision of electricity with minimum interruptions, (Fumagalli & Schiavo, 2009). Moreover, improved service quality ensures sustainable operations, detection, effective monitoring systems, and transparent recovery of bills that reduce the pressure on electricity prices and resultantly reduce the benefit of stealing electricity (Jamil & Ahmad, 2018). When service quality is poor, it affects the monitoring and detection processes of electricity theft; therefore, electricity theft would increase in the form of meter tempering and hooking.

improve the efficiency of distribution utilities were only introduced in 2005. Following the rate of return, NEPRA does not offer rewards or incentives to improve the quality of services. In contrast, distribution utilities in Pakistan are assigned targets to reduce transmission and distribution losses, but NEPRA's data reveals that losses are increasing along with poor service quality.[2] (NEPRA, 2018). It is in this context, therefore, that this timely analysis of Pakistan is being undertaken through this study.

The quality of services offered by the electricity distribution utilities is integral to the distribution service and pricing decisions. Service quality directly affects the quality of electricity supply and value for price while indirectly affecting all economic activities that require electricity (Mirza & Mushtaq, 2022). An essential aspect of service quality is reliability (Engineroom, 2012). Reliability of electricity distribution implies the monitoring and detection system for electricity theft; therefore, in the absence of a state-of-the-art detection and monitoring system, electricity theft will increase.

Furthermore, improved service quality ensures sustainable operations and transparent recovery of bills that reduce the pressure on electricity prices (Jamil & Ahmad, 2018). Improved service quality implies an improvement in quality-of-service parameters. These parameters are a holistic combination of reliable supply, theft monitoring, detection systems, and transparency in the recovery of bills. Therefore, improvement in service quality can ensure the reduction in losses and the efficient recovery of bills. Contrary to this, losses that increase because of stealing electricity deteriorate the service quality by increasing the load on the distribution system (Depuru et al., 2011). On the demand side, electricity theft leads to inefficient consumption, while on the supply side, it deteriorates the bill recovery (Mushtaq & Mirza, 2021a, b; Waleed & Mirza, 2020). Therefore, it is essential to understand how service quality affects electricity theft.

We also evaluate the effect of the probability of detection on illegal consumption of electricity in Pakistan. It is believed that with a better understanding of factors causing illegal consumption, distribution utilities can reduce monetary loss associated with electricity theft (Yurtseven, 2015).

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[2] Electricity theft is a significant portion of system losses comprising electricity theft, which is increasing as per NEPRA's State of Industry Report (2018). Electricity theft is the most common form of meter tempering and illegal connections (hooking).

Such understanding can help distribution utilities reduce the prevalence of illegal consumption that disturbs, firm revenues, investment decisions, and service quality (Yurtseven, 2015). The preventive measures to reduce illegal consumption should focus on socio-economic factors. However, the effectiveness of these measures depends on the collaborative work of distribution utilities and law-making agencies (Mimmi & Ecer, 2010). Thus, this study will guide policymakers in reaching collaborative policy decisions between the administration and law-enforcement agencies.

1.2 Significance of Research

The issue of electricity theft in developing countries is complex. For instance, most electricity theft cases are not reported, nor are penalties awarded to the suspected thieves. Therefore, there is a need to understand the issue of electricity theft and consumer behavior by considering Pakistan's contextual, theoretical, and ground realities.

In this regard, our study makes the following contributions to the literature on electricity theft: studies have yet to attempt to empirically estimate the causes of electricity theft by considering the theoretical basis and behavioral determinants. Furthermore, our empirical model differs from the existing literature as no current empirical research examines the interaction of service quality with rainfall on electricity theft in Pakistan.

This study is structured as follows: Section 2 reviews the literature and discusses the trends in electricity distribution losses in Pakistan; Section 3 discusses the empirical model and methodology, while Section 4 presents the results; Section 5 concludes the study and suggests policy measures to reduce the illegal consumption of electricity in Pakistan.

2. Literature Review

Literature on electricity theft can be categorized into two main streams: The first strand focuses on the socio-economic determinants of electricity theft. Smith (2004) investigated the determinants of electricity theft in 102 countries and found that income is the primary determinant. In a country-level analysis, Gümüşdere (2004) and Steadman (2009) found that raising income and education levels effectively reduced electricity theft in the electricity market. Depuru et al. (2011) revealed that rising unemployment rates and illiteracy were the major socio-economic factors affecting electricity theft in India. Along with income, many other socio-economic determinants, including population, social capital, and sectoral productivity, were indicated to have primarily influenced the stealing behavior of consumers (Yurtseven, 2015). Gaur & Gupta (2016) found that higher tax-to-GDP ratio, bill recovery, and income negatively affect electricity theft in India.

The other stream of literature analyzes the role of administrative and institutional quality in determining consumers' stealing behavior. For instance, Smith (2004) found poor governance, poor accountability, high corruption, and political instability to be the main determinants of electricity theft.

Mimmi & Ecer (2010) studied the determinants of electricity theft in Brazilian slums. They found that the poor quality of electricity supplied to these areas is the main reason people steal electricity. Poor service quality refers to interrupted electricity supply, poor monitoring and detection systems, and lack of transparency. Poor system maintenance and meter detection and monitoring systems motivate illegal electricity consumption. Moreover, the study found that institutional weaknesses, including corruption, poor law enforcement, and political support, encouraged people in India to steal electricity (Depuru et al., 2011; Golden & Min, 2012). Similar findings were confirmed by Tasdoven, et al. (2012), who found the effectiveness of governance tools in reducing electricity theft in the Turkish electricity market. Mutebi, et al. (2014) confirmed that corruption in distribution utilities was the main reason for increased electricity theft. Dike, Obiora, et al. (2015) examined the determinants of electricity theft in Nigeria and found that corruption, the absence of accountability, poor bill collection, ineffective institutions, and poor law enforcement were significant factors affecting illegal electricity consumption. Lewis (2015) examined the relationship between electricity theft and electricity disruption. He used production functions to determine the cost of electricity disruption on the economy but found minimum economic damage from power disruption in Jamaica. In a cross-sectional analysis of 1,532 households in Ghana, Yakubu et al. (2018) found that high tariff rates, ineffective law enforcement, and poor supply quality were the dominant motivating factors for electricity theft.

Regarding the literature on the electricity market in Pakistan, we found limited empirical evidence concerning the causes and determinants of electricity theft. For instance, Mirza et al. (2015) analyzed time series data from 1970 to 2010 to examine the determinants of electricity theft using aggregate data. The study found a significant effect of income, number of customers, and tariff rates on electricity theft in Pakistan. Naz & Ahmad

(2013) investigated the causes of the electricity crisis in four districts of Karachi by collecting data from 2,500 households. They found that load-shedding – also known as rolling blackouts - was the primary cause of high electricity theft in Karachi. For Pakistan, Jamil & Ahmad (2014) is an exceptional study that examined the impact of economic activity on the illegal consumption of electricity and found that per capita income and fines negatively affect the losses, while the probability of detection, load shedding, and electricity price positively affect electricity theft.

The literature review has highlighted several gaps in the existing collection of studies, specifically regarding electricity distribution utilities in Pakistan. First, there needs to be more literature examining the effect of socio-economic factors on electricity theft in Pakistani distribution utilities. Second, to the best of our knowledge, empirical work has yet to be available which has exclusively studied the effect of service quality on electricity theft in Pakistan. Therefore, this study fills the gaps in the existing literature by examining the effect of social, economic, administrative, and service quality variables on electricity theft in Pakistan.

3. Empirical Model

3.1 Estimation Equation

This study follows Jamil & Ahmad (2014) for specifying the empirical model of electricity theft for electricity distribution utilities in Pakistan. Following Cullmann & Nieswand (2015) and Caporale, Amor & Rault (2009), we use a one-year lag of electricity theft to control for steady-state convergence in examining the stealing behavior of consumers. The log-linear equation of electricity theft is represented in equations 1 and 2.

$$ET_{it} = \alpha_0 + \alpha_1 ET_{i,t-1} + \alpha_2 Prob_{it} + \alpha_3 F_{it} + \alpha_4 P_{it} + \alpha_5 Y_t + \alpha_6 SAIFI_{it} + \alpha_7 SAIDI_{it} + \alpha_8 T_{it} + \alpha_9 Temp_{it} + \alpha_{10} R_{it} + u_{it} + \varepsilon_{it} \quad (1)$$

$$ET_{it} = \alpha_0 + \alpha_1 ET_{i,t-1} + \alpha_2 Prob_{it} + \alpha_3 F_{it} + \alpha_4 P_{it} + \alpha_5 Y_t + \alpha_6 CAIDI_{it} + \alpha_7 T_{it} + \alpha_8 Temp_{it} + \alpha_9 R_{it} + u_{it} + \varepsilon_{it} \quad (2)$$

Where ET refers to the amount of electricity consumed illegally; Prob corresponds to the probability of detection; F reflects the fine charged for detection; P shows electricity price; Y reflects income; T reflects time trend; Temp refers to minimum temperature; and R reflects rainfall; u_{it} corresponds to the unobserved individual effects while ε_{it} is the i.i.d error term with mean zero and variance constant. Electricity theft is defined as the illegal consumption of electricity, which includes fraud, illegal hookups, billing irregularities, and unpaid bills (Smith, 2004). As the data on meter tempering, hookups, and billing irregularities is not available separately for distribution utilities in Pakistan, this study follows Gaur & Gupta (2016), Jamil & Ahmad (2014), Golden & Min (2012) and Steadman (2009) to use transmission and distribution losses as a proxy to measure electricity theft.

In this analysis, we consider income and electricity prices as social factors that influence consumers' decision to steal electricity. Income is expected to impact electricity theft negatively (Gümüşdere, 2004; Mirza et al., 2015; Gaur & Gupta, 2016). The price of electricity is an economic factor expected to positively affect the unlawful use of electricity (Mirza et al., 2015; Jamil & Ahmad, 2014, 2019).

Two administrative variables, namely, the probability of detection and being charged with fines, are included to capture the effect of criminal laws on electricity theft from distribution utilities. The probability of detection is computed by taking the ratio of detection bills and the number of consumers served by each distribution utility. In contrast, the fine is computed by dividing the fine charged by the number of cases detected. Theoretically, it is reasonable to assume that a high probability of detection increases the risk of being caught. Therefore, we expect a negative effect on the probability of detection and fines for electricity theft (Steadman, 2009).

The rate of electricity theft is influenced by various factors that prioritize quality. These factors encompass System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), and Consumer Average Interruption Duration Index (CAIDI). SAIFI and SAIDI are essential components of the quality standards mandated for distribution utilities by the National Electric Power Regulatory Authority (NEPRA, 2005). According to the Performance Standards (Distribution) Rules of 2005, NEPRA has established acceptable limits for SAIFI and SAIDI, set at 13 interruptions and 14 minutes, respectively (NEPRA, 2005).

In equation 2, we adopt the approach presented by LaCommare & Eto (2008), substituting SAIFI and SAIDI with CAIDI, which serves as a globally recognized parameter for assessing the quality of services. CAIDI refers to the duration of interruption per customer affected by interruptions over a year and is calculated by dividing SAIDI by SAIFI. Enhanced service quality offered by distribution utilities reduces the number and duration of power interruptions. Conversely, a decline in these parameters increases the likelihood of electricity theft and renders the utilities' distribution system more susceptible to technical and non-technical losses (Mimmi & Ecer, 2010; Dike et al., 2015; Yakubu et al., 2018).

3.2 Data

This study employs panel data from eight electricity distribution utilities from 2006 to 2018. Following the literature, we use transmission and distribution losses as a proxy for electricity theft[3] (Gaur & Gupta, 2016; Golden & Min, 2012; Smith, 2004). Data for system losses, SAIFI, and SAIDI was obtained from various issues of state of industry reports. In contrast, the electricity price data was extracted from distribution utilities' financial statements. Data for detection and fine charges probability are taken from DISCO performance statistics published by Pakistan Electric Power Company (PEPCO). Time series data for GDP growth is extracted from several issues of the Pakistan Economic Survey, whereas data for minimum temperature and rainfall is obtained from the Pakistan Meteorology Department. The rainfall and temperature data for this study have been acquired from the Pakistan Metrology Department. Comprehensive daily rainfall and temperature records have been accessible for various geographical locations across Pakistan since 1990. These daily data points determined the annual average rainfall and temperature values. We calculated the annual average values for each electricity distribution utility using data from the respective headquarters within the utility's coverage area. Among the climatic factors influencing the electricity distribution system in Pakistan, thunderstorms and torrential rains have demonstrated the most significant impact. Consequently, we have incorporated the minimum monthly temperature as an indicator of the influence of these factors during the extended summer season in Pakistan.

[3] According to the State of Industry Reports, more than 50 % of transmission and distribution losses come from unbuilt electricity consumption, primarily due to electricity theft and related irregularities (NEPRA, 2018). As data on electricity theft is not available for Pakistan, this study uses transmission and distribution losses as a proxy to measure it.

Table 1: Descriptive Statistics

Variables	Units	Mean	Std. dev	Minimum	Maximum
Dependent variable					
Transmission and Distribution losses (Proxy for electricity theft)	GWh	1884.52	1131.644	659	5424.77
Administrative Factors					
Probability of Detection	Numbers	0.138	0.299	0.0014	1.479
Fine	Million Rs	0.004	0.004	0.00004	0.0321
Socio-economic Factors					
Electricity price	Price/KWh	9.345	3.602	2.85	16.703
GDP growth	%	4.142	1.461	1.604	5.898
Service quality parameters					
SAIFI	Numbers	6332.23	31595.31	0.03	219162.7
SAIDI	Minutes	881322.3	7517048	0.1	76.1
CAIDI	Minutes/ Numbers	565.37	4882.16	0.03	49833
Weather Variables					
Minimum temperature	Degree C	16.796	3.712	7.3	21.7
Rainfall	millimeter	476.571	429.619	8.8	1732.4

3.3 *Econometric Method*

We employ the one-step system GMM approach to estimate the dynamic panel models presented in equations 1 and 2[4]. Arellano and Bover (1995) and Blundell and Bond (1998) proposed a one-step system GMM estimator to control for potential endogeneity arising from a lagged dependent variable in our models. The literature indicates that an increase in electricity theft increases the financial burden for distribution utilities, inhibiting utilities from investing in quality improvement (Yurtseven, 2015). Similarly, poor service quality increases interruptions, which leads to customer dissatisfaction. Thus, poor service quality increases the benefit of stealing electricity for the hours that power is available. Therefore, we employed a one-step system GMM estimator to control for potential endogeneity between electricity theft and service quality.

Estimating dynamic panel models with standard estimators, namely pooled ordinary least squares (POLS), brings econometric complications because of the correlation between the lagged dependent variable and the error term, even if the error is not serially correlated. One-step system GMM eliminates the potential bias of endogeneity as it takes

[4] For the application of System GMM on dynamic panel data, see Arellano & Bover (1995), Blundell & Bond (1998), Baum et al. (2003), and Roodman (2009).

the difference of level equation and assumes that the first difference of instruments is not correlated with utility-specific effects (Roodman, 2009).

One-step System GMM estimator is considered superior to other dynamic panel estimates, particularly for smaller samples. Simulation analysis of Blundell & Bond (1998) revealed that the first difference GMM estimator produces estimates with downward bias because of weak instruments in a small sample. To solve this problem, the one-step system GMM estimator produces efficient estimates, assuming that the first difference instrumental variable is not correlated with a fixed effect (Bond et al., 2001). Although the two-step system GMM is considered a superior estimator in employing the instrumental variables, it underestimates the standard deviation and produces less reliable estimates than the one-step estimator (Blundell et al., 2000). Taking the lead from these arguments, we use a one-step System GMM approach to estimate the potential factors affecting electricity theft in Pakistan.

The reason for using a one-step system GMM estimator is two-fold: First, empirical work on GMM estimates has emphasized that the results of one-step GMM are superior as efficiency gains in two-step GMM are modest (see Arellano & Bond, 1991; Blundell & Bond, 1998; Blundell & Bond, 2000; Bond, 2002). Second, applying the two-step system GMM to a limited sample produces a standard error with downward bias (Bond et al., 2001; Soto, 2009). Therefore, following Teixeira & Queirós (2016), the study uses a one-step system GMM due to fewer cross-sections (8 distribution utilities) than the period (13 years). The estimations were performed using Stata 14.

Furthermore, endogeneity concerning service quality has been dealt with by taking the lag of service quality variables as instruments in the estimation. Neanidis, et al. (2017) and Cullmann & Nieswand (2016) have used a similar strategy. The validity of the instruments has been assessed by the Sargan test for overidentification and the difference-in-Sargan test for exogeneity. The Sargan test for over-identification tests the validity of an entire set of instruments used in the analysis. The Sargan test for over-identification tests the null hypothesis that all instruments used in the analysis are uncorrelated with the error term (Barugahara, 2013). The acceptance of the null hypothesis indicates that over-identified restrictions are valid. However, this test has little power when a large subset of excluded instruments is used. The difference-in-Sargan test, which tests a subset of original orthogonality conditions (Baum et al., 2003), is more helpful. It tests the null hypothesis that all instruments are valid (Baum et al., 2003).

Moreover, this study uses Arellano & Bond (AB) statistics to check the serial correlation in disturbance terms. These statistics test the null hypothesis that the disturbance term in the first difference equation is serially correlated (Baum et al., 2003). For a well-specified model, the null hypothesis must be rejected, indicating that all moment conditions employed in the analysis are valid.

4. Results and Discussion

This study applies several tests to one-step system GMM estimation. The problem of endogeneity arising from the quality of service has been tackled by taking the lag of service quality variables as instruments in the estimation. Neanidis, et al. (2017) and Cullmann & Nieswand (2016) have used a similar strategy. Following Roodman (2009), we utilize the lag of losses as an instrument for the first difference equation and treated predetermined variables and the lag of service quality as an instrument for the level equation. The validity of instruments has been tested using Sargan tests. These tests are presented in Table 2, which indicates that in models 1 and 2, the number of instruments is less than the number of observations. As the number of instruments is greater than the number of endogenous variables in equations 1 and 2, we employ the Sargan test for over-identification to test whether all moment conditions are jointly exogenous. Table 2 shows that the probability value of the Sargan test is 0.135 and 0.521 in model 1 and model 2, respectively, which indicates that over-identification restrictions in both models are valid. The probability value of the difference-in-Sargan test is 0.908 for model 1 and 0.964 for model 2, indicating that the instruments used in the analysis are valid (Baum et al., 2003). For accurate moment conditions, error terms in the system GMM estimates have no serial correlation (Arellano & Bond, 1991). The results of the Arellano Bond test in models 1 and 2 confirm that error terms in difference equation follow the AR (1) process, whereas insignificant probability values of AR (2) reject the hypothesis of higher order autocorrelation.

The coefficient of lagged electricity theft (T&D losses) in model 1 is positive and statistically significant, indicating that the theft in the previous year explains 0.34 percent of the variation in electricity theft. It is plausible to believe that a consumer who is involved in the illegal consumption of electricity will continuously do so until it is detected. We find a positive and statistically significant effect of the time trend on electricity theft, indicating that losses of electricity distribution utilities increase with time. A possible reason for this positive effect is that electricity distribution utilities do not regularly upgrade and maintain the distribution network. As time passes, the poorly managed system contributes to losses (Yurtseven, 2015).

Considering the effect of administrative factors on electricity theft (T&D losses), model 1 in Table 2 shows the significant effect of these factors on reducing the theft rate in electricity distribution utilities in Pakistan. The coefficient of the probability of detection is -0.15, showing that with a 1 percent increase in the probability of detection, consumers reduce illegal consumption by 0.15 percent. This finding is similar to Steadman (2009), who argued that consumers prefer to steal electricity until discovered. Model 1 in Table 2 further highlights that with a 1 percent increase in fine charged for stealing electricity, electricity theft (T&D losses) decreases by 0.15 percent. The fine is the monetary loss for stealing electricity. However, consumers bear this loss only if they are convicted and fined. Therefore, we assume that an increase in the fine helps distribution utilities in curtailing electricity theft. These findings are theoretically justified by various studies that argue that the probability of detection and punishment can aid in reducing crime (Becker, 1968; Ehrlich, 1973; Brier & Fienberg, 1980; Eide et al., 2006; Jamil & Ahmad, 2014).

Turning towards socio-economic factors, we can find statistically insignificant impacts of electricity prices while observing significant effects of income on electricity theft in model 1. The insignificant effect of electricity price on illegal consumption contrasts with the theory because, theoretically, when the price of electricity increases, it becomes expensive for consumers to afford it; thus, consumers prefer to steal. Electricity prices in Pakistan are administratively determined; however, the government subsidizes electricity for customers' well-being (Mirza et al., 2021). Therefore, the stealing behavior of consumers in Pakistan is not determined by the electricity price. This finding contrasts with Jamil & Ahmad (2014) and Mirza et al. (2015). Negative and statistically significant effects of per capita income are in line with Gaur & Gupta (2016), Yurtseven (2015), and Mirza et al. (2015). Model 1 in Table 2 indicates that with a 1 percentage point increase in national income, consumers tend to reduce electricity theft (T&D losses) by 0.151 percent.

We assume the positive effect of improved service quality on reducing electricity theft (T&D losses). To confirm this assertion, SAIFI, SAIDI, and CAIDI are service quality variables in the model. The coefficient on SAIDI shows a positive and statistically significant effect on electricity theft, indicating that the benefits of consuming illegal electricity increase with the increase in the duration of the interruption. The coefficient on SAIDI in model 1 is positive and significant at a 1 percent level of significance, indicating that distribution utilities experience a 0.06

percent increase in electricity theft (T&D losses) if the duration of power interruption increases by 1 percent.

Climatic conditions also affect the stealing behavior of consumers because the benefits of consuming illegal electricity increase in adverse climatic conditions (Yurtseven, 2015). Model 1 in Table 2 shows that electricity theft (T&D losses) increases with an increase in minimum temperature and rainfall. Findings indicate that consumers steal 0.06 percent of electricity if the minimum temperature rises by 1 degree Celsius. Our findings echo those of Jamal and Ahmad (2014). Electricity is consumed for cooling or heating purposes, and as a result, any change in weather conditions can affect the electricity-stealing behavior of consumers.

Model 2 presents the estimates of equation 2 in which CAIDI is used to capture the effect of service quality on electricity theft. Model 2 shows the convergence as the point estimate of lagged electricity theft is smaller than 1, signifying that the previous behavior of consumers to use illegal electricity affects their current behavior. The coefficient of lagged T&D losses shows that a 1 percent increase in theft in the previous year leads to a 0.52 percent increase in theft in the current year. Like model 1, we find positive and statistically significant effects of time on consumer behavior to steal electricity.

Table 2: Estimates of Electricity theft of Distribution utilities: The dependent variable is electricity theft

Variables	**One-Step System GMM**			
	(1)	**(2)**	**(3)**	**(4)**
T&Dlosses$_{,t-1}$	0.345*	0.522***	0.224*	0.343**
	(0.190)	(0.161)	(0.132)	(0.140)
Probability of detection	-0.156*	-0.137**	-0.236***	-0.120*
	(0.0933)	(0.0673)	(0.0770)	(0.0664)
Fine	-0.158*	-0.150*	-0.190**	-0.171*
	(0.0864)	(0.0873)	(0.0802)	(0.0883)
Electricity Price	-0.263	0.205	0.216	-0.0845
	(0.241)	(0.268)	(0.277)	(0.280)
GDP growth	-0.151**	-0.236***	-0.224***	-0.280***
	(0.0725)	(0.0890)	(0.0834)	(0.0902)
SAIFI	0.0237		-0.147	
	(0.0466)		(0.0974)	
SAIDI	0.0669*		0.151**	
	(0.0361)		(0.0608)	
CAIDI		0.123**		0.171***
		(0.0508)		(0.0653)
Time	0.0997**	0.148***	0.178***	0.185***

Variables	One-Step System GMM			
	(1)	(2)	(3)	(4)
	(0.0432)	(0.0452)	(0.0465)	(0.0471)
Minimum temperature	0.0613**	0.0494**	0.0717***	0.0600***
	(0.0274)	(0.0224)	(0.0227)	(0.0227)
Rainfall	0.000142	-0.000222	0.000114	0.000113
	(0.000119)	(0.000145)	(0.000278)	(0.000287)
$Rainfall \times saifi$			0.000203*	
			(0.000112)	
$Rainfall \times saidi$			-0.00009	
			(0.00006)	
$Rainfall \times caidi$				-0.00005
				(0.00007)
Constant	2.173**	0.257	0.916	1.638
	(0.942)	(1.179)	(1.134)	(1.241)
AR (1)	0.010	0.005	0.007	0.003
AR (2)	0.337	0.135	0.115	0.132
Sargan test for over-identification ($prob > \chi^2$)	0.135	0.521	0.514	0.141
Difference in Sargan test of exogeneity($prob > \chi^2$)	0.908	0.964	0.642	0.962
Number of observations	66	53	45	52
Number of groups	8	8	8	8
Number of time periods	13	13	13	13
Number of instruments	22	31	43	36

Note: One-step system GMM estimates of equations 1 and 2 are reported where the endogenous variable is $T\&Dlosses_{i,t-1}$.
The instruments used in our models include the first difference of electricity theft, the first difference of probability of detection, the first difference of SAIFI, the first difference of SAIDI, the lag of SAIDI, the lag of SAIDI, and the lag of CAIDI.
We treated the lag of SAIFI, SAIDI, and CAIDI as instruments to eliminate the endogeneity of service quality.
Due to data limitations of fines and probability of detection for 2011 and data unavailability of rainfall for GEPCO from 2006 to 2011, the number of observations decreased. Further, the sample size decreased because of the number of instruments included in the estimation.
The probability values of the Arrellano–Bond, Sargan test, and the Difference in Sargan tests are reported in the table.
***, ** and * show the Significance at the 1%, 5% and 10% levels, respectively.

Table 2 shows that the insignificant effect of electricity price in model 2 contrasts with the theoretical understanding, as an increase in the price increases the benefits of stealing electricity, compared to the risks associated with being charged with a fine for said theft. It is worth noting that consumers do not get involved in stealing electricity if it is provided at lower tariff rates, as the monetary benefit of stealing electricity will be lower than the social and psychological cost of committing a crime (Jamil & Ahmad, 2019). The coefficient of CAIDI is positive and statistically significant, indicating that a 1 percent increase in the duration of interruption leads to a 0.12 percent increase in electricity theft (T&D losses). This finding aligns with Mimmi & Ecer (2010), who observed that poor supply quality increases the theft of electricity. Our findings on the role of service quality parameters are consistent and supported by literature (Smith, 2004; Tasdoven et al., 2012; Colden & Min, 2012; Depuru et al., 2011). However, these studies examined the role of institutional quality rather than service quality standards on electricity theft.

Model 2 reveals positive and statistically significant effects of temperature on electricity theft (see Table 2). The estimates of minimum temperature show that a 1 degree Celsius increase in minimum temperature increases electricity theft (T&D losses) by 0.04 percent, which is in line with Yurtseven (2015).

Models 3 and 4 are estimated by adding the interaction terms of SAIFI, SAIDI, and CAIDI with rainfall. The purpose is to examine customers' behavior toward electricity theft during rainfall. It is evident that on rainy days, consumers respond to the number of interruptions rather than the duration, as the continuity of the electricity supply gets disturbed during rain (Domijan et al., 2003). This discontinuity of the provision of services increases the theft of electricity. Results of models 3 and 4 are presented in Table 2. The robustness of one-step GMM estimates is verified in both models because the number of instruments is less than the number of observations.

Similarly, the Arellano-Bond estimator test confirms that valid moment conditions are applied, whereas residuals of the first difference yield higher-order correlation. The Sargan and Difference-in-Sargan tests also confirm that all instruments and a subset of instruments are valid and that joint moment conditions are exogenous. Since the models are well-specified, we proceed with further findings.

Table 2 confirms the convergence in models 3 and 4 because the coefficient of lagged electricity theft is positive, statistically significant, and less than 1. This indicates that 0.22 percent (model 3) and 0.34 percent (model 4) variation in the current amount of electricity theft (T&D losses) is explained by the electricity theft rate in the previous year. Estimates of models 3 and 4 confirm the positive and statistically significant effect of time on electricity theft, showing that losses of electricity distribution utilities increase with time.

Consistent with models 1 and 2, an improved administration helps reduce electricity theft concerning Pakistan's distribution utilities. Models 3 and 4 show in Table 2 that an increase in the probability of conviction and fine charged increases the risk of stealing electricity and decreases electricity theft. As far as socioeconomic factors are concerned, we find a negative and statistically significant effect of income on electricity theft (T&D losses), which is in line with the empirical findings of Gaur & Gupta (2016), Jamil & Ahmad (2014), and Mirza et al. (2015).

We find negative and statistically significant effects of SAIDI and CAIDI in models 3 and 4, respectively. Better quality of service allows the utilities to take administrative actions effectively and implement laws by charging fines. Furthermore, improved service quality ensures the reliable provision of electricity, which further helps reduce transmission and distribution losses (Yu et al., 2009).

Consistent with models 1 and 2, temperature shows a positive and statistically significant effect on T&D losses, as variations in weather conditions disturb the carrying capacity of transmission and distribution lines that contribute to power interruptions and blackouts. Including the interaction terms of service quality variables with rainfall provides us with considerable results. The coefficient on the interaction of SAIFI and rainfall is positive and statistically significant, while the interaction term of SAIDI and rainfall is statistically insignificant. From these findings, it is evident that on rainy days, consumers respond to the number of interruptions rather than the duration of interruptions because the continuity of the electricity supply gets disturbed during rain. This discontinuity of service provision increases the theft of electricity; consequently, T&D losses increase.

5. Conclusion and Recommendations

Electricity theft in Pakistan is increasing rapidly and requires the urgent attention of policymakers. To plan effective policy measures, policymakers must understand the factors affecting consumer's behavior toward stealing electricity. Therefore, this study pursues to identify socio-economic, administrative, and service quality factors affecting electricity theft in Pakistan. We use panel data from eight electricity distribution utilities from 2006 to 2018 and employ a one-step system GMM procedure to estimate the models.

We find a negative and statistically significant effect of income on stealing behavior, indicating that an increase in income increases the pecuniary benefits, thus reducing electricity theft (T&D losses). In Pakistan, administrative factors significantly affect the behavior of consumers who consume electricity illegally. Findings indicate that an increase in the probability of detection and fine decreases electricity theft (T&D losses). Further, an increase in the duration of interruptions increases electricity theft (T&D losses). Considering the effects of weather conditions in the models provides us with important insights. The positive and statistically significant effect of temperature and rainfall on electricity theft shows that extreme weather conditions contribute to poor service quality, further increasing transmission and distribution losses.

Based on the empirical analysis's findings, we suggest policymakers attract private investment in the distribution network, which will help reduce the financial problems of distribution utilities emerging from the issue of circular debt.

Since we observe an insignificant effect of electricity price on theft, NEPRA is advised to reconsider its tariff determination policy and adopt the marginal cost pricing rule for tariff determination in the long run. This may help distribution utilities recover their cost and make quick payments to power generation companies. The regulatory body is suggested to encourage the installation of advanced metering technologies into the distribution system in the long run, which will help to reduce transmission and distribution losses.

Our estimates reveal that service quality has a vital role in changing consumers' behavior regarding stealing electricity. Therefore, distribution utilities are advised to initiate effective measures to improve service quality, including system up-gradation, bill recovery, and scheduled maintenance in the short run. Our findings highlight that unpaid electricity bills are piling up, and the recommended solution to this problem lies in dynamic installments. These installments may be added to the current bills of defaulters. The Central Power Purchasing Agency Guarantee Limited (CPPA-G) is advised to improve the administrative structure of distribution utilities by separating electricity retail functions from distribution.

6. Limitations of the Study

We have faced certain limitations in data availability. For instance, data for rainfall from 2006 to 2011 for GEPCO is unavailable. Similarly, data for the probability of detection and fines are missing for 2008 and 2011 for all electricity distribution utilities. The data for fines and probability of detection is produced by Pakistan Electric Power Company (PEPCO) in DISCOs Performance Statistics. Due to the unavailability of DISCOs Performance Statistics in 2008 and 2011, we could not include the data for these two years in the estimations. Lastly, data on electricity theft, including meter tempering, billing irregularities, and hookups, is not available for Pakistan. Therefore, this study uses system losses to measure electricity theft.[5]

Credit authorship contribution statement:

Iqra Mushtaq: Conceptualization, Methodology, Software, Writing – original draft.

Faisal Mehmood Mirza: Validation, Data, Resources, Supervision, Writing – review & editing.

Declaration of competing interest:

The authors declare that they do not have any personal or financial conflict of interest that could affect the outcome of this research.

[5] Gaur & Gupta (2016). Jamil & Ahmad (2014), Golden & Min (2012), and Steadman (2009) used transmission and distribution losses to measure electricity theft.

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Appendix A

Table A1: Correlation between Service quality and Metrological Variables

	Minimum temperature	Rainfall
SAIFI	0.0874	-0.0455
SAIDI	0.0079	0.0548
CAIDI	-0.2066	-0.0701