Pakistan Journal of Social Sciences (PJSS)
Vol. 41, No. 4 (2021), pp.709-721

Services Quality, System Losses and Electricity Supply: Empirical Evidence from Electricity Distribution Utilities in Pakistan

Iqra Mushtaq
PhD Scholar, Department of Economics,
University of Gujrat, Gujrat, Pakistan

Faisal Mehmood Mirza
Associate Professor, Department of Economics,
University of Gujrat, Gujrat, Pakistan
Email: faisal.mirza@uog.edu.pk

Abstract:
This study estimates the effect of services quality and system losses on the electricity supply using data from eight electricity distribution utilities in Pakistan. One-step system GMM estimation results find a negative and statistically significant effect of services quality on electricity supply by the electricity distribution utilities. The results further confirm the existence of the non-linear relationship between system losses and electricity supply. The estimated threshold level of system losses is 7 percent which is below the current level of losses at 18 percent. Our results reinforce that services quality standards for distribution utilities at their current level are not being determined accurately by NEPRA. NEPRA is suggested to revise its required performance standards and use the threshold level of system losses as a benchmark to set the targeted losses for each utility.

Keywords: Electricity Supply, Services Quality, System Losses, Distribution Utilities, GMM, Pakistan

I. Introduction

Reliable and uninterrupted supply of electricity is essential for the sustainable development of economies around the globe (Wahid, Khattak and Ali, 2016). Electricity distribution networks play a fundamental role in ensuring reliable, continuous, and affordable delivery of electricity. Distribution of electricity is a complex and integrated process in which electricity passes through a composite network comprising of transmission lines, girds, distribution lines, transformers, and cables (Hussain et al., 2017). When electricity is generated in the power plants, step-up-transformers are used to increase the voltage for effective transportation in transmission and distribution lines while step-down-transformers decrease its voltage before it safely reaches the end-users. Due to inefficiencies in the transmission and distribution networks, electricity generated in power generation plants is not optimally distributed to end customers as some percentage of electricity is lost in the distribution process, formally known as transmission and distribution losses. Thus, the reduction in transmission and distribution losses carries utmost importance for ensuring a reliable and uninterrupted supply of electricity.

Date of Acceptance and Available Online: 06 October , 2021

The inefficacy of transmission and distribution networks is mainly manifested in technical and non-technical losses. Technical losses arise because of aging infrastructure, poor conducting material, and physical limits of the cables and transformers while non-technical losses include electricity theft, meter tampering, illegal connections, and unpaid bills (Surana and Jordaan, 2019). Existing literature indicates that the overhead electricity transmission and distribution mechanisms are subject to various physical limits such as temperature, humidity, snow, pressure, and moisture (Jamasb, Orea and Pollitt., 2012). The extent of technical and non-technical losses and their benchmarking in distribution networks is inconclusive. Some empirical estimates suggest that an efficient network suffers from less than 6 percent of technical losses while an inefficient network experiences more than 9 percent of technical losses (Surana and Jordaan, 2019). Hence, it is expected that a distribution network with reliable and up-to-date system may also experience a few percentages of technical losses.

Recently, the preferences in electricity transmission and distribution networks have changed in such a way that alongside continuous electricity supply, the services quality standards are in spotlight for the optimal services delivery. The quality of electricity supply is defined as the ability of the network to perform in an appropriate manner for the provision of reliable and uninterrupted electricity to the end-users (Tesařová, 2011). In an ideal world, the electricity supply would remain reliable while frequency and voltage would remain at the required engineering level (Fumagalli and Schiavo, 2009). However, in the real world, electricity supply gets distorted and the frequency and voltage levels may deviate from the required levels. Improved services quality is thus essential to manage the continuity of electricity supply and to control for technical and non-technical losses. Moreover, services quality enables distribution utilities to meet customer demands in an efficient manner because it directly affects the distribution of electricity (Iwayemi, 2001, 08; Okafor, 2008; Opeyemi et al., 2019; Sihombing, 2010; Adom et al., 2019; Nababan, 2017).

Pakistan being a developing country requires reliable supply of electricity along with improved services quality. In this regard, National Electric Power Regulatory Authority (NEPRA) determines the targeted level of system losses and advises distribution companies to take effective measures to reduce these losses on annual basis. However, the distribution utilities have largely failed to achieve the set targets and incurred a loss of Rs 38 billion to the national exchequer in FY19 (NEPRA, 2019).

The losses of distribution utilities are increasing over time because of an aging distribution network, outdated wiring, inadequate capacity of transmission lines, inappropriate distribution operations, and a high ratio of low voltage to high voltage lines (Qazi and Jahanzaib, 2018). Consequently, these excessive transmission and distribution losses combined with tariff rates set below the marginal cost of electricity generation and poor bills collection have dampened the performance of electricity distribution sector (Qazi and Jahanzaib, 2018; Rizvi and Mirza, 2019). Along with this, the institutional shortcomings in managing the electricity networks delay the decision-making process which further affects the services quality of electricity distribution utilities. Together, poor services quality, inadequate capacity, high transmission, and distribution losses, and weak regulatory framework reduce the supply of electricity to end-users (Rizvi and Mirza, 2019). The inadequate capacity of the distribution network affects the operational performance of power plants by deferring the issuance of licenses for new generation plants (NEPRA, 2010). Therefore, it is important to examine the potential economic and utility-specific factors affecting the electricity supply in Pakistan.

In this regard, the prime objective of this study is to empirically investigate the impact of services quality on electricity supply in Pakistan. Another objective is to estimate the relationship between system losses and electricity supply of distribution utilities in Pakistan. The contribution of this study to the existing literature is two-fold. To the best of our knowledge, this study provides the first econometric evaluation of the impact of services quality on electricity supply in Pakistan. Secondly, this study estimates the nonlinear relationship between distribution losses and electricity supply in Pakistan. This estimation helps in determining the acceptable level of distribution losses below which the electricity supply would not deteriorate. Many studies have attempted to explain a negative and linear relationship between system losses and electricity supply[1] however, to the best of our knowledge, Adom et al. (2019) is the only study that argued that system losses exhibit a non-linear relationship with electricity supply as it is not possible for distribution utilities to completely eliminate system losses. The investigation of an acceptable level of system losses will provide a unique benchmark for each distribution utility and enable them to make cost and investment decisions while considering their threshold level of system losses. The estimates of threshold-level of system losses for each distribution utility would help the policymakers in identifying the difference in operational conditions across distribution utilities which would be used for designing new targets for improving quality while minimizing losses.

This study is organized in the following manner. Section 2 provides the theoretical framework to probe into the determinants of electricity supply. Section 3 explains the methodology and data whereas section 4 discusses the results. Section 5 concludes the study and suggests suitable policy measures to improve services quality and electricity supply in Pakistan.

II. Theoretical Model

According to the neoclassical theory, the supply of a good depends upon its price, the price of other goods, and the production technology (Adom et al., 2019). Supply function of a typical commodity can thus be represented as in equation (1).

$$E = f(P_o, P_r, T) \qquad (1)$$

Where E denotes supply of goods, P_0 represents own price, Pr is the price of other goods and T indicates the production technology. By relating neoclassical theory to the electricity market, electricity supply function of a distribution utility can be expressed as a function of electricity price, price of fuel, and technology.

$$E_{s,i} = f(P_{e,i}, P_{f,i}, T_i) \qquad (2)$$

Along with these factors, electricity supply is equally influenced by investment decisions, market size, and services quality standards (Nababan, 2017; Okafor, 2008; Demers and Roy, 2006). Investment indicates the capacity expansion in the distribution network while system losses are used to measure the operational and managerial

[1] For details see Nababan (2017), Iwayemi (2008); Opeyemi et al. (2019).

efficiency in the sector (Nababan, 2017; Iwayemi, 2008). Equation (3) thus presents a more representative electricity supply function of a distribution utility.

$$E_{s,i} = f(P_{o,i}, P_{f,i}, I_i, M_i, L_i, QOS_i) \quad (3)$$

Equation (3) is deterministic in nature. To covert it into an econometric model, stochastic component ε is added to the equation. This equation is augmented with the term "A" which captures the effect of knowledge and experience on system operations. Following equation represents the general form of electricity supply equation of a distribution utility:

$$E_{s,it} = Af(P_{o,it}, P_{f,it}, I_{it}, M_{it}, L_{it}, QOS_{it}, \varepsilon_{it}) \quad (4)$$

III. Empirical Model

Cobb-Douglas production function has been employed to estimate the electricity supply function of distribution utilities in Pakistan.

$$E_{s,it} = AP_{e,it}^{\beta} P_{f,t}^{\gamma} I_{it}^{\chi} M_{s,it}^{\xi} L_{it}^{\phi} QOS_{it}^{\psi} e^{it} \quad (5)$$

Where e reflects the exponential term. We use log-linear transformation to econometrically estimate equation (5) and the transformed equation is reflected as equation (6).

$$lnE_{s,it} = \alpha_0 + \beta lnP_{e,it} + \gamma lnP_{f,t} + \chi lnI_{it} + \xi lnM_{s,it} + \phi lnL_{it} + \psi lnQOS_{it} + \varepsilon_{it} \quad (6)$$

The end-user tariff rate has been used to capture own price effect on electricity supply. Price of high-speed diesel has been used to capture the cost of alternate fuel. We use utility-wise customer growth as a proxy to measure the market size of an electricity distribution utility. It is believed that distribution utilities may increase electricity supply with increase in its market size. We follow Saleem (2007), Senyonga and Bergland (2014), and Mirza, Mushtaq and Ullah (2017) to choose customer growth as a measure of market size. Literature indicates that increase in investment of distribution utilities positively affects the availability of electricity supply while increase in system losses reduces the supply of electricity (Sihombing, 2010; Nababan, 2017; Iwayemi, 2008). Services quality is mainly influenced by the number and duration of power interruptions and transmission and distribution losses (NEPRA, 2005). Thus, we use NEPRA's approved services quality variables namely SAIFI, SAIDI into our analysis.

System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) are reliability indexes used to examine the quality of supply in electricity market. SAIFI refers to total number of power supply interruptions per consumer in a year whereas SAIDI refers to the duration of power supply interruption per customer in a year. As evident from existing empirical findings[2], SAIFI and SAIDI provide different effects on the cost of distribution utilities, therefore, to avoid these complications, and to extensively analyze the role of services quality on the provision of

[2] Mirza, Rizvi, and Bergland (2021) found the opposite effect of SAIFI and SAIDI on the technical efficiency of distribution companies in Pakistan.

electricity to end-users, we run another model which uses CAIDI as a measure of services quality. Customer Average Interruption Duration Index (CAIDI) is another reliability index that refers to the average duration of interruption per customer affected by power interruptions in a year. The inclusion of CAIDI to capture the effect of services quality is motivated by LaCommare and Eto (2008) and Stenberg (2012). We also assume that electricity supply by distribution utilities depends on the provision of electricity in previous years (Adom et al., 2019). Therefore, we included a one-year lag of provided electricity in supply the function. This leads us to the following econometric specification of electricity supply of distribution companies.

$$lnE_{s,it} = \alpha_0 + \beta lnP_{e,it} + \gamma lnP_{f,t} + \chi lnI_{it} + \xi lnCusgrowth_{it} + \phi lnL_{it} + \psi_1 lnSAIFI_{it} + \psi_2 lnSAIDI_{it} + \zeta lnE_{si,t-1} + \varepsilon_{it} \quad (7)$$

$$lnE_{s,it} = \alpha_0 + \beta lnP_{e,it} + \gamma lnP_{f,t} + \chi lnI_{it} + \xi lnCusgrowth_{it} + \phi lnL_{it} + \psi_1 lnCAIDI_{it} + \zeta lnE_{si,t-1} + \varepsilon_{it} \quad (8)$$

Equation (7) and (8) reflect our baseline models in which a linear relationship between distribution losses and electricity supply is formulated. The baseline models allow us to assume “zero tolerance rate” in the electricity distribution network for system losses[3]. However, in reality, this might not be true in electricity markets where system losses are bearable up to a certain level and this level does not deteriorate the supply of electricity (Adom et al., 2019). Hence, we assume a non-linear relationship between system losses and electricity supply by the distribution utilities. To capture this non-linear relationship, the square of transmission and distribution losses has been included in our baseline models that yield the extended specification of supply function of distribution utilities as mentioned in equations (9) and (10).

$$lnE_{s,it} = \alpha_0 + \beta lnP_{e,it} + \gamma lnP_{f,t} + \chi lnI_{it} + \xi lnCusgrowth_{it} + \phi_1 lnL_{it} + \phi_2 lnL_{it}^2 + \psi_1 lnSAIFI_{it} + \psi_2 lnSAIDI_{it} + \zeta lnE_{si,t-1} + \varepsilon_{it} \quad (9)$$

$$lnE_{s,it} = \alpha_0 + \beta lnP_{e,it} + \gamma lnP_{f,t} + \chi lnI_{it} + \xi lnCusgrowth_{it} + \phi_1 lnL_{it} + \phi_2 lnL_{it}^2 + \psi_1 lnCAIDI_{it} + \zeta lnE_{si,t-1} + \varepsilon_{it} \quad (10)$$

Here E_s refers to electricity supply, P_e corresponds to price of electricity, P_f reflects the price of fuel, I refers to the investment of distribution utilities, cusgrowth refers to the customer growth, L corresponds to losses, L^2 reflects the square of losses, SAIFI refers to System Average Interruption Frequency Index, SAIDI represents System Average Interruption Duration Index and CAIDI reflects the Consumer Average Interruption Duration Index (Ortmeyer, 2010).

A. Econometric Methods

The econometric specifications of the supply function depict an endogeneity problem because of the presence of lagged electricity supply on the right-hand side of

[3] “Zero tolerance rate” hypothesis believes that electricity distribution utilities are efficient enough to completely reduce system losses. However, engineering-wise it is not possible because of some unavoidable losses that occur in in transmission process (Saeed et al., 2020).

equations (7), (8), (9), and (10). It makes the model dynamic in nature and changes the interpretation of the model. In econometric models when no lagged variable is included in the analysis, the explanatory variables show complete information. Parameter estimates of these models with simple econometric methods yield inconsistent estimates. Therefore, this study uses dynamic panel estimators, One-step System GMM to meet study objectives (Arellano and Bover 1995; Blundell and Bond 1998).

One-step System GMM

Arellano and Bond (1991) and Arellano and Bover (1995) developed a convenient framework to produce asymptotically efficient estimates. AB estimator augments level equation with differenced equation and allows for using additional lags of endogenous variables as instruments. To remove the utility-specific effects from the level equation, the difference of the instruments is used as exogenous variables. It is assumed that these instruments are not correlated with utility-specific effects because;

$$E(\Delta Es_{it}\eta_i) = 0 \quad (11)$$
$$E(\Delta x_{it}\eta_i) = 0 \quad (12)$$

If these conditions are met, $\Delta Es_{it-1}$and Δx_{it-1}become valid instruments for level equation as;

$$E(\Delta Es_{it-1}\epsilon_{it}) = 0; t = 3,4 \dots, T \quad (13)$$
$$E(\Delta x_{it-1}\epsilon_{it}) = 0; t = 3,4, \dots, T \quad (14)$$

The reason for using one-step system GMM is two-folded: first, empirical work on GMM estimates has emphasized the results of one-step GMM because studies showed modest efficiency gains in using two-step GMM (see Arellano and Bond, 1991; Blundell and Bond, 1998; Blundell and Bond., 2000; Bond, 2002). Second, the application of the two-step system GMM on a limited sample produces standard error with a downward bias. Therefore, following Teixeira and Queirós (2016), we apply a one-step system GMM due to fewer cross-sections (8 distribution utilities) than the time period (13 years).

B. Specification Tests

To test for the validity of the instruments, this study has employed Sargan test for over-identification and difference in Sargan test for exogeneity. The null hypothesis of the former test is that the over-identified instruments are not correlated with disturbance terms (Barugahara, 2013). Sargan test of over-identification follows χ^2distribution with $\mathrm{I} - \mathrm{K}$ degrees of freedom where I reflects the number of instruments while K is the number of independent variables in the model. Acceptance of null hypothesis indicates that instruments are uncorrelated with the error term. Difference in Sargan test for exogeneity tests the orthogonality of moment conditions. The null hypothesis of difference in Sargan test for exogeneity is that the specific variables used as instruments are proper and valid (Baum, Schaffer and Stillman, 2003). The consistency of one-step system GMM estimates depends on the assumption that $(\Delta\epsilon_{it}\Delta\epsilon_{it-2}) = 0$ (Blundell and Bond, 1998). Therefore, Arellano-Bond test is carried out to test for the first-order serial correlation in the disturbance term. AB test tests the null hypothesis that errors in the first difference equation are serially correlated (Baum et al., 2003). For a well-specified model, the null hypothesis is rejected indicating that all the moment conditions employed in the analysis are valid.

C. Data

This study has employed the panel data of eight electricity distribution utilities by covering the time period of 2006 to 2018. The data on electricity supply, distribution losses, customer growth, SAIFI, SAIDI, and CAIDI is taken from the State of Industry reports annually published by NEPRA (NEPRA, 2006:2018). The data on electricity price and the total investment is taken from financial statements of distribution utilities while the data on the price of high-speed diesel is extracted from the Statistical Supplement of Pakistan Economic Survey (GoP, 2006:2018). The summary statistics of these variables are presented in Table 1.

Table 1: Summary Statistics

Description	Units	Mean	Std. dev	Minimum	Maximum
Electricity supply	GWh	8379.65	3659.43	3381	20448.5
Electricity price	Price/KWh	9.34	3.59	2.87	16.70
Fuel Price	Price/Ltrs	73.60	22.82	36.31	108.40
Investment	Million Rs	103002.1	61230.99	11453.62	257872
Customer growth	Percentage	0.03	0.10	-0.49	0.54
Losses	Percentage	18.77	9.41	7.69	39.16
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

IV. Results and Discussion

A. Estimates of the Baseline Model

One-step system GMM results based on equations (7) and (8) of baseline models 1 and 2 are presented in Table 2. To test for the robustness of one-step system GMM estimates, several tests have been applied to models 1 and 2. As number of instruments used in the analysis is greater than the number of endogenous variables, we test for the over-identification by applying Sargan test. The acceptance of the null hypothesis satisfies the over-identification restriction for the moment conditions, indicating that moment conditions used in estimation are valid for our estimates. The results of AB test for models 1 and 2 reject the presence of higher-order serial correlation in the error term of the first differenced equation (Arellano and Bond, 1991).

The coefficient of lagged electricity supply in model 1 is positive and statistically significant showing that 0.97 percent variation in current supply of a distribution utility is explained by electricity supply in the previous year. Our estimates provide significant evidence of inertia in electricity supply of distribution utilities indicating that inefficiency in the electricity supply of distribution utilities remains persistent. We observe a positive but statistically insignificant effect of electricity price on its supply in model 1 which is in line with Wahid et al. (2016) and Audu and Apere (2013). The possible reason for the statistically insignificant price is that end-user tariff rates are determined administratively, below the marginal cost of production (Mirza et al., 2021). Another reason is that electricity distribution utilities are state-owned monopolies and profit maximization is not their primary objective, thus, supply by these utilities does not respond to the electricity prices (Wahid et al., 2016). As expected, the price of alternate fuel is negative and statistically significant at 1 percent level of significance. Model 1 reveals that 1 percent increase in the price of high-speed diesel increases the cost burden of distribution utilities, resultantly; utilities reduce supply of electricity by 0.15 percent. This finding is similar to Iwayemi (2008).

The coefficients on investment and customer growth have positive signs, indicating a positive effect of these variables on electricity supply. Model 1 in table 2 indicates that 1 percent increase in the investment of distribution utilities increases electricity supply by 0.08 percent. Likewise, 1 percent increase in customer growth increases electricity supply by 1.28 percent. Adom et al. (2019) also found a positive and statistically significant effect of market size on electricity supply. As distribution utilities are responsible to provide electricity to end-users, their supply increases with the increase in market size.

Model 1 indicates that distribution utilities reduce electricity supply by 0.07 percent for 1 percent increase in transmission and distribution losses, which is in line with Ubi et al. (2012) and Nababan (2017). High transmission and distribution losses indicate poor operational efficiency thus reduce electricity supply (Adom et al., 2019). As expected, SAIFI and SAIDI show opposite effects on electricity supply. One-step GMM estimates for model 1 indicate that 1 percent increase in the duration of power outages reduces electricity supply by 0.012 percent. Contrary to Nababan (2017), our estimates indicate that increase in the duration of power interruptions increases the cost burden of distribution utilities on account of system maintenance and network up-gradation and reduces electricity.

Model 2 provides GMM estimates of the baseline model where CAIDI has been used as services quality variable and the results are reported in table 2. While estimating linear relationships, the study finds the positive and statistically significant effect of lagged electricity supply on current supply of distribution utilities. In accordance with Sambo (2008) and Opeyemi et al. (2019), we find positive and statistically significant effect of investment and customer growth on electricity supply of distribution utilities. The coefficients of these variables show that 1 percent increase in investment and customer growth leads to 0.09 and 1.05 percent increase in electricity supply, respectively.

Based on the estimates of services quality variables, we find a negative and statistically significant effect of system losses and CAIDI on electricity supply. Similar to Adom et al. (2019), results highlight that due to 1 percent increase in distribution losses, electricity supply reduces by 0.04 percent. The coefficient of CAIDI reveals that 1 percent increase in consumer duration of power outages leads to 0.01 percent decrease in electricity supply of the distribution companies. This finding is similar to Opeyemi et al. (2019) who conducted a time series analysis of electricity production in Nigeria and found a positive and statistically significant effect of institutional quality on electricity supply.

B. Estimates of Nonlinear Model

Models 3 and 4 present the results of nonlinear relationship between transmission and distribution losses and the electricity supply of distribution utilities. The results of models 3 and 4 indicate that AB test rejects the null hypothesis that errors in the first difference equation are serially uncorrelated at AR (3). The results of Sargan test for over-identification indicate that instruments are not correlated with disturbance term (table 2) whereas the difference in Sargan test for exogeneity verifies that all instruments used in the analysis are valid. These results indicate that the nonlinear relationship between electricity supply and system losses holds for the case of electricity distribution utilities in Pakistan.

Table 2: Estimates of Electricity supply of Distribution utilities: Dependent variable is electricity supply				
One Step System GMM				
Variables	**Linear Model**		**Nonlinear model**	
	(1)	(2)	(3)	(4)
Electricity supply $_{i,t-1}$	0.974***	0.979***	1.019***	1.065***
	(0.0243)	(0.0199)	(0.0221)	(0.0477)
Electricity Price	0.0348	0.0254	0.0372	0.0456
	(0.0363)	(0.0381)	(0.0345)	(0.0396)
Fuel Price	-0.157***	-0.191***	-0.127***	-0.123***
	(0.0433)	(0.0450)	(0.0348)	(0.0388)
Investment	0.0829***	0.0982***	0.0513***	0.0652***
	(0.0185)	(0.0143)	(0.0127)	(0.0154)
Customer growth	1.284***	1.050***	1.224***	1.558***
	(0.240)	(0.180)	(0.124)	(0.176)
Losses	-0.0745**	-0.0430*	1.323***	1.350*
	(0.0366)	(0.0232)	(0.507)	(0.689)
Losses square			-0.219***	-0.217*
			(0.0838)	(0.114)
Saifi	0.0145		0.0108	
	(0.00975)		(0.00696)	
Saidi	-0.0120*		-0.0224***	
	(0.00650)		(0.00621)	
Caidi		-0.0145*		-0.0193*
		(0.00791)		(0.0100)
Intercept	0.101	-0.00756	-2.126***	-2.889**
	(0.270)	(0.257)	(0.809)	(1.311)
AR (1)	0.000	0.000	0.000	0.000
AR (2)	0.457	0.529	0.053	0.194
AR (3)	-	-	0.594	-
Sargan test for over identification $(prob > \chi^2)$	0.584	0.350	0.112	0.283
Difference in Sargan test of exogeneity$(prob > \chi^2)$	0.466	0.489	0.431	0.850
Number of observation	94	94	94	94
Number of groups	8	8	8	8
Number of time periods	13	13	13	13
Number of instruments	31	46	59	31
Threshold level			**6.88%**	**6.78%**

One step system GMM estimates of Eq. (7, 8, 9 and 10) are reported where endogenous variable is electricity supply$_{i,t-1}$
Probability values of the Arrellano–Bond, Sargan test and Difference in Sargan tests are reported in the table.
***, ** and * show the Significance at the 1% , 5% and 10% levels, respectively.
Threshold level of system losses is calculated by taking partial derivative of supply with respect to losses and assuming resulting equation equal to zero.

The estimates of models 3 and 4 verify that current electricity supply of distribution utilities depends on the electricity supply in the previous year. The coefficient of lagged electricity supply is positive and statistically significant indicating that a 1 percent increase in electricity supply leads to 1.01 and 1.06 percent increase in current supply in models 3 and 4, respectively. Model 3 and 4 in table 3 have positive and statistically significant effects of investment while the negative and statistically significant effect of alternate fuel price on electricity supply. The positive effect of investment is justified because distribution utilities increase investment expenses to install new technology and to improve their distribution networks, which in turn reduces system losses and enhances electricity supply. Like Adom et al. (2019), models 3 and 4 show a positive and statistically significant effect of customer growth on electricity supply indicating that distribution utilities positively respond to market size. Further, we find negative and statistically significant effects of SAIDI (model 3) and CAIDI (model 4) on electricity supply showing that improved services quality enhances the reliability of electricity supply to end-users.

GMM estimates confirm the existence of a non-linear relationship between electricity supply and system losses of distribution utilities in Pakistan. In model 3, the coefficient on transmission and distribution losses shows a positive and statistically significant effect on electricity supply while the coefficient of square of losses yields a negative and statistically significant effect on electricity supply. Estimates indicate that due to 1 percent increase in transmission and distribution losses, distribution utilities increase the supply of electricity by 1.32 percent. However, the squared term of losses reveals 0.21 percent reduction in electricity supply with 1 percent increase in losses-squared. The analysis indicates that an initial increase in system losses increases electricity supply to a certain level and beyond this level, increase in losses causes a reduction in electricity supply. Estimated threshold level of system losses is 6.88 percent, showing that system losses are acceptable for a distribution utility up to 6.8 percent because, at this level, these losses do not deteriorate the supply of electricity to end-users.

Model 4 also confirms the existence of an inverted U-shaped relationship between electricity supply and transmission and distribution losses. The results reveal that 1 percent increase in losses increases electricity supply by 1.35 percent initially. Contrary to this, the coefficient on losses-squared shows that beyond the threshold level, 1 percent increase in the losses reduces electricity supply by 0.21 percent. The estimated threshold level with these estimates is 6.78, which is similar to the threshold level obtained from Model 3. It is pertinent to note that this threshold level is far below the targeted level of distribution losses determined by NEPRA. NEPRA determines the target level of losses for each distribution utility on annual basis depending upon their costs. Currently, average transmission and distribution losses of distribution utilities are 18 percent which indicates that distribution utilities need to cut down losses by 12 percent to remain at the acceptable level of losses[4]. From these estimates, we argue that distribution utilities in Pakistan have already crossed the threshold limit of losses which signifies our synthesis that distribution utilities are operating with poor services quality. Therefore, our estimates identify the need of reviewing the performance parameters in terms of transmission and distribution losses. This requires distribution utilities to incur prudent investment in reducing losses and improving services quality.

V. Conclusions and Policy Recommendations

This study pursues two main objectives as we estimate the threshold level of system losses and measure the effect of services quality on the electricity supply of distribution utilities in Pakistan. For this purpose, panel data from eight electricity

---

[4] Adom et al. (2019) argued that it is not engineering-wise possible for distribution network to eliminate system losses because of the technical losses. Technical losses are not avoidable as they occur in system equipment during the process of transmission and distribution (Saeed et al., 2020). Hence, there must be an acceptable level of losses that do not affect electricity supply

distribution utilities from 2006 to 2018 has been used. We employ a One-step system GMM to estimate the relationships. The findings provide significant evidence of inertia in the electricity supply equation which indicates that any inefficiency in the electricity supply in the previous year sustains in the future. We find a positive but statistically insignificant effect of electricity price on its supply because electricity tariff rates in Pakistan are determined by the government; which are far below the marginal cost.

The study confirms the nonlinear relationship between electricity supply and distribution losses. The estimated threshold level is about 7 percent. Currently, average transmission and distribution losses stand at 18 percent, which is much higher than the estimated threshold level, implying that distribution utilities should reduce system losses by about 11 percent, on average. As electricity distribution utilities have crossed the acceptable level of losses, it is required to increase investment into the sector to help utilities to improve their operational performance. We further find that required services quality standards are not accurately determined by NEPRA because the estimated threshold level of system losses is far below the allowed losses. We further find that none of the distribution utilities remained successful in meeting these targets, which are much higher than the acceptable level. Therefore, we argue the need for reviewing the performance parameters by keeping in view the estimated threshold level of losses.

On the basis of these estimates, NEPRA is suggested to adopt the marginal cost pricing rule for tariff determination which will improve the financial condition of distribution utilities. Talking lead from the estimates of the threshold level, NEPRA is suggested to use the threshold level of system losses to set a benchmark for performance by distribution utilities on the basis of their operating conditions. This study further suggests encouraging private investment in the distribution network. Along with the private investment, NEPRA should incentivize distribution utilities in installing advanced technologies in distribution network which will help in reducing technical losses and improving services quality to ensure the reliable supply of electricity to the end-users.

References

Adom, P. K. (2017). The long-run price sensitivity dynamics of industrial and residential electricity demand: the impact of deregulating electricity prices. Energy Economics, 62, 43-60.

Adom, P. K., Agradi, M. P., & Bekoe, W. (2019). Electricity supply in Ghana: The implications of climate-induced distortions in the water-energy equilibrium and system losses. Renewable Energy, 134, 1114-1128.

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. The review of economic studies, 58(2), 277-297.

Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. Journal of econometrics, 68(1), 29-51.

Audu, N. P., & Apere, O. T. (2013). The Dynamics of Demand and Supply of Electricity in Nigeria. Dynamics, 3(3).

Baum, C. F., Schaffer, M. E., & Stillman, S. (2003). Instrumental variables and GMM: Estimation and testing. The Stata Journal, 3(1), 1-31.

Barugahara, F. (2013). A Study on Growth, Inflation and Inequality (Doctoral dissertation, University of Leicester).

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. Journal of econometrics, 87(1), 115-143.

Blundell, R., & Bond, S. (2000). GMM estimation with persistent panel data: an application to production functions. Econometric reviews, 19(3), 321-340.

Bond, S. R. (2002). Dynamic panel data models: a guide to micro data methods and practice. Portuguese economic journal, 1(2), 141-162.

Demers, D., & Roy, R. (2006). Impacts of climate change on a hydrological regime and effects on hydroelectricity production in the province of Quebec, Canada. In European Conference on Impacts of Climate Change on Renewable Energy Sources, Iceland, June.

Fumagalli, E., & Schiavo, L. L. (2009). Regulating and improving the quality of electricity supply: the case of Italy. European Review of Energy Markets, 3(3), 1-27.

GOP. (2006:2018). Economic Survey of Pakistan. Islamabad: Government of Pakistan.

Hussain, Z., Memon, S., Dhomeja, L., & Abbasi, S. (2017). Analysis of non-technical electrical power losses and their economic impact on Pakistan. Sindh University Research Journal-SURJ (Science Series), 49(2).

Iwayemi, A. (2001). Nigeria's fractured Development: The energy connection. An inaugural lecture at the University of Ibadan, Ibadan: Oyo state.

Iwayemi, A. (2008). Investment in electricity generation and transmission in Nigeria: issues and options. International Association for Energy Economics, 7(8), 37-42.

Jamasb, T., Orea, L. and Pollitt, M. (2012), "Estimating the marginal cost of quality improvements: The case of the UK electricity distribution companies", Energy Economics, 34(5), 1498-1506.

LaCommare, K. H., & Eto, J. H. (2008). Tracking the reliability of the us electric power system: An assessment of publicly available information reported to state public utility commissions (No. LBNL-1092E). Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States).

Mirza, F. M., Rizvi, S. B. U. H., & Bergland, O. (2021). Services quality, technical efficiency and total factor productivity growth in Pakistan's post-reform electricity distribution companies. Utilities Policy, 68, 101156.

Mirza, F. M., Mushtaq, I., & Ullah, K. (2017). Assessing the efficiency dynamics of post reforms electric distribution utilities in Pakistan. Utilities Policy, 47, 18-28.

Nababan, T. S. (2017). Analysis of factors affecting the electricity supply in Indonesia.

NEPRA. (2005). Performance Standard (Distribution) Rules 2005. Islamabad: National Electric Regulatory Authority.

NEPRA. (2006:2018). State of Industry Report. National Electric Power Regulatory Authority. Islamabad: National Electric Regulatory Authority.

NEPRA. (2019). Performance evaluation report of distribution companies for the year 2018-19. Islamabad: National Electric Power Regulatory Authority, 2019.

Okafor, E. E. (2008). Development crisis of power supply and implications for industrial sector in Nigeria. Studies of Tribes and Tribals, 6(2), 83-92.

Opeyemi, A., Uchenna, E., Simplice, A., & Evans, O. (2019). Renewable energy, trade performance and the conditional role of finance and institutional capacity in sub-Sahara African countries. Energy Policy, 132, 490-498.

Ortmeyer, T. (2010). A unified index for power distribution reliability/power quality indices. In Proceedings of 14th International Conference on Harmonics and Quality of Power-ICHQP 2010 (pp. 1-6). IEEE.

Qazi, U., & Jahanzaib, M. (2018). An integrated sectoral framework for the development of sustainable power sector in Pakistan. Energy Reports, 4, 376-392.

Rizvi, S. B. U. H., & Mirza, F. M. (2019). Politico-Economic Barriers to Technical Efficiency in Restructured Electricity Distribution Utilities in Pakistan: A Discourse Analysis. Pakistan Journal of Social Sciences (PJSS), 39(3).

Saeed, M. S., Mustafa, M. W., Hamadneh, N. N., Alshammari, N. A., Sheikh, U. U., Jumani, T. A., ... & Khan, I. (2020). Detection of Non-Technical Losses in Power Utilities—A Comprehensive Systematic Review. Energies, 13(18), 4727.

Saleem, M. (2007). Benchmarking and regulation for the electricity distribution sector in Pakistan: Lessons for developing countries. South Asia Economic Journal, 8(1), 117-138.

Sambo, A. S. (2008). Matching electricity supply with demand in Nigeria. International Association of Energy Economics, 4, 32-36.

Sambo, A. S. (2008). Matching electricity supply with demand in Nigeria. International Association of Energy Economics, 4, 32-36.

Senyonga, L., & Bergland, O. (2014, September). Incentive regulation, efficiency improvements and productivity growth in electricity distribution utility: A Norwegian Case. In Energy Economics: New Challenges & Solutions. International Association for Energy Economics.

Sihombing, J. (2010). Analisi periawaran Energi Listrik di propirisi sumatera utara (Skripsi). Fakultus Ekonomi Universitas Sumatra Utara, Medan.

Surana, K., & Jordaan, S. M. (2019). The climate mitigation opportunity behind global power transmission and distribution. Nature Climate Change, 9(9), 660-665.

Tesařová, M. (2011). Power quality and quality of supply.

Teixeira, A. A., & Queirós, A. S. (2016). Economic growth, human capital and structural change: A dynamic panel data analysis. Research policy, 45(8), 1636-1648.

Ubi, P. S., Effiom, L., Okon, E. O., & Oduneka, A. E. (2012). An econometric analysis of the determinants of electricity supply in Nigeria. International Journal of Business Administration, 3(4), 72.

Wahid, F, Khattak, R. & Ali, S. (2016). The Determinants and Forecasting of Electricity Supply in Pakistan. Industrial Engineering Letters 6 (1).