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Abstract

We address the causes of electricity shortage in Pakistan by examining data over the period 1971-2010 with time series analysis. The novelty lies in characterizing energy shortage via an index comprising the demands of electricity, gas and oil as well as via the information of public electricity supply. In particular, this index enables a simple empirical approach where energy shortage cannot be directly measured as data. Our main findings are as follows: first, end-consumers adjust their energy demand to the prices only in long run. Second, under-utilization of installed power generation capacity encourages fossil fuel consumption for private electricity. Third, uninterrupted electricity supply could be attained through regulating private electricity generation. Fourth, the relative demand for electricity increases and then decreases with real income in relation to gas and oil. Overall, our investigation implies that price adjustments tactics adopted by the government are not effective policies to deal with power shortage if oriented to short-run impacts. Rather, the government should focus on improving utilization rate of installed power plants and re-channeling the use of oil and gas for public electricity generation. Otherwise, energy shortage shall be worsened with economic growth in Pakistan.

Key Words: energy shortage, energy consumption index, electricity price, oil prices
JEL Classification: Q57, Q58

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1 Introduction

Energy is the mainstay of an economy in the contemporary world. Power shortage may harm the overall welfare of a country in number of ways, for example, by decreasing total output of energy intensive sectors (Kessides (1993)). In recent decades, Pakistan has failed to meet vigorously the increasing energy demand due to various reasons including over-reliance on fossil fuels for power generation, swelling oil prices, climate variation, inadequate alternative energy sources, insufficient technological advancement and so forth (Kucukali and Baris (2010), Chaudhry (2010) and Hasan et al. (2012)). In 2011, the total energy shortfall outnumbered 6,000 Megawatt (MW) compared to a shortfall of 4000 MW in 2004 (Amer and Daim (2011)). Extended power outage in urban areas reached 8-10 hours in a day, while blackouts in rural areas peaked 20 hours at a stretch. Literature shows energy consumption is directly linked with industrial production, economic expansion and standard of living in Pakistan. Persistent power shortage may retard economic growth of the country if the issue remains unsolved (Siddiqui (2004); Bhutto and Karim (2007); Khan and Ahmed (2009) and Aqeel and Butt (2001)).

Numerous studies have shown that own electricity generation using backup power generators is an obvious indicator of power shortage because it is generally more expensive than the electricity bought from the government (See Beenstock (1991), Adenikinju (2005), Beenstock et al. (1997) and Steinbuks and Foster (2010) for reference). In the context of Pakistan, two principal factors governing own electricity production are as follows: (1) Pakistan is an energy deficient country and (2) domestic power production is not regulated by the government. Pasha et al. (1989) find that the 1980's energy crisis of Pakistan resulted in enormous investment in power generators. Today, availability of sophisticated and affordable backup generators has made private electricity generation a habitual practice for even a middle income family.

Existing literature, in the context of Pakistan, have focused on investigating dynamics of electricity consumption while the key supply side determinants are not considered in the analysis. For instance, Khan and Ahmed (2009) examine energy demand at dis-aggregate level (coal, electricity, gas) using annual time series data over 1972-2007. Their regression model comprises per capita energy consumption, per capita real income and energy prices. Their study highlights that real income and price affect demands for coal and electricity positively and negatively respectively in short run only. Income and price elasticities of gas are higher than those of coal and electricity. Jamil and Ahmad (2010) study the relationship between electricity consumption, its prices and real income in Pakistan using annual time series data over the period 1960-2008 using vector error correction models (VECM). Their research shows unidirectional causality running from economic output to electricity consumption and price at national, residential and manufacturing sectors in long run and a bi-directional causality between production level and electricity consumption (and prices) in short run for manufacturing and agricultural sectors.

Chaudhry (2010) employs panel data from 63 countries from 1998-2008 to study the relationship between electricity consumptions, real per capita income and electricity prices. Findings of this research suggest that electricity consumption at both household and national levels increases with increase in real per capita income in Pakistan. Output function analysis shows that electricity shortage will cut production of small scale industries which does not have own electricity generation capacity, whereas it will increase the cost of production for large firms from own electricity production from expensive inputs. All these studies, however, do not provide empirical evidence of the underlying problem, e.g., what causes electricity shortage.

Only one recent study by Hasan et al. (2012) tries to investigate dynamics of electricity shortage using the power outage data by Karachi Electric Supply Corporation (KESC) for one city of Pakistan "Karachi." They employ monthly data over the period Jan-2009 to Dec-2011 for Pearson correlation, vector auto-regressive (VAR) and Tobit models to explore inefficiencies of power sectors. This study confirms the existence of huge power shortfall which is increasing over time, harming economic activity and highlights the fact that long power breakdowns cannot reduce the shortfall. It further underscores that the past electricity shortage determines present price levels. However, this approach cannot be adopted to conduct a study at national or more aggregate levels in the absence of power outage data.

Through extensive survey of empirical literature, we find that there are few studies to directly examine the causes of power shortage at a national level considering the supply side of electricity.[1] Although some researchers have made useful policy recommendations to curb energy crisis of Pakistan with descriptive analysis, some empirical questions still remain: what is the cause of power shortage? what are supply side bottlenecks? How do end-users behave during power shortfalls? What will be the effective policy to solve energy shortage? Since the existing literature on energy focuses more on energy demand, income and price levels, we look at a new aspect of analysis, that is, supply sides of electricity in Pakistan together with some key variables of prices and incomes. More specifically, we seek to answer the aforementioned open questions analyzing the relative demand of electricity, oil and gas by relating it with the supply side.

Our analysis clarifies the determinants of electricity shortage in Pakistan at aggregate and sectoral levels (for household, industrial and agricultural sectors). For this, we develop and use a unique energy consumption index, ECI, as a proxy for electricity deficiency. ECI is a relative demand of fossil fuels compared to that of electricity. The index is obtained by dividing the sum of oil and gas consumption by electricity consumption. In this calculation, we converted all types of energy consumption measurements into a single unit (i.e. tons of oil equivalent (TOE)). Under an ideal situation of adequate power supply, ECI should follow a steady pattern of growth over time. Provided a state of acute power shortage where oil and gas are used as a substitute of electricity, ECI fluctuates in both short run and long run in the context of Pakistan. Under these assumptions, ECI is a reliable indicator to capture electricity shortage.[2]

We employ an Engle and Granger two steps approach and an error correction model to assess the factors responsible for electricity shortage in Pakistan. Using annual data of electricity, gas and oil consumption, electricity and oil price, real GDP per capita, utilization of installed ca-

[1] A straightforward assessment of power shortage is not possible due to unavailability or unobservability of the relevant power outage data at a national level.

[2] ECI fluctuates when electricity shortage and blackouts occur in Pakistan because people use self-generators to back up electricity using oil and gas. When there is no blackout or no electricity shortage, it means that power plants provide sufficient electricity with people. The use of oil and gas under no blackout or no shortage should be relatively smooth so that ECI must be smooth as well. Therefore, a fluctuation of ECI is considered to be attributed to the heavy use of backup generators when electricity shortage and blackouts occur in Pakistan.

pacity (in percentage) for electricity production and electricity production from thermal (fossil fuels and coal) and non-thermal (hydel and nuclear) sources, present study obtains the following main findings: first, end-consumers adjust their energy demand to the prices only in long run. Second, under-utilization of installed power generation capacity encourages fossil fuel consumption for private electricity. Third, uninterrupted electricity supply could be attained through regulating private electricity generation. Fourth, the relative demand for electricity increases and then decreases with real income in relation to gas and oil. Overall, our investigation implies that price adjustments tactics adopted by the government are not effective policies to deal with power shortage if oriented to short-run impacts. Rather, the government should focus on improving utilization rate of installed power plants and re-channeling the use of oil and gas for public generation. Otherwise, energy shortage shall be worsened with economic growth in Pakistan.

The rest of this paper is structured as follows: Section 2 describes the demand and supply of energy and electricity shortage in Pakistan with a brief overview of electricity, oil and gas sectors of Pakistan. The model, methodology and data are discussed in section 3. Empirical results and their interpretation are discussed in section 4, while conclusion, policy implications and recommendation are presented in the final section.

2 Overview of the energy sector in Pakistan

The shortage of energy and its related problems have continued to restrict Pakistan's economic growth severely due to its under-developed, inefficient and poorly managed infrastructure.[3] Pakistan government is reported not to have made any serious effort to expand generation capacity to support rapid economic expansion during the recent decade (Khan and Ahmed (2009)). Consequently, when power demand outnumbers supply, government adopts load management through load-shedding and price increasing tactics. As an immediate remedy of national power crisis, the Government of Pakistan (GOP) installed several rental power plants (RPP) for about

[3] Power theft, bribe and corruption are common in the energy sector of Pakistan and many utilities are still receiving subsidies (Khan and Ahmed (2009)).

1156.1 MW generation capacity in 2008-09 (Transparency International-Pakistan (2010)). Thermal power expansion of RPPs was criticized by many researchers from the beginning of this project. Asian Development Bank (2010) claimed that the project would not be sufficient enough to eradicate load-shedding, rather, it would exert upward pressure in power production costs. Under RPP scenarios, the end-user will have to bear an increase in the tariff by 80%. Present media reports show that per unit production cost (of particular RPP's) has exceeded Pakistan Rupee (hereafter, PKR) 40, whereas the average selling price per unit is PKR 7.

Despite a hefty increase in electricity prices after 2008, there still exists a significant gap between power generation cost and actual recovery. GOP, therefore, has to subsidize PKR 30 (for some RPPs) per unit to keep the price stable. In 2012, just after 3 years of placement of the project, RPP turns out to be a multi-million corruption scam.[4] Moreover, an increase in world oil prices set enormous upward pressure on the cost of power generation, which ultimately exacerbated power supply situation. Primary energy supply per capita witnessed a decline of 1.25% and 3.09% in 2000 and 2010 respectively as shown in Table 1. The figures for 2011 and 2012 are expected to present the even worse scenario. On the consumption side, all types of energy consumption decreased in 2008-09. Oil, gas and electricity consumption shrank by 0.9%, 0.5% and 1.7% respectively as reflected in Table 2. However, oil and gas consumption recovered in the 2010. However, electricity consumption faced another decline of 1.7%.

2.1 Why electricity shortage in Pakistan?

Inefficiencies, strengths and challenges of power sectors in Pakistan have been studied by several authors, although there are few empirical works that characterize the issue. Many scholars note that power production, management and consumption sides are responsible for current electricity shortage in Pakistan. In Pakistan, production and distribution inefficiencies include more than 20% transmission and distribution losses, over-reliance on thermal power production and under-utilization of installed capacity for power production.

[4]Please see Asian Development Bank (2010), the summary of Supreme Court verdict on RPP case 2012 (International The News (2012)), and Pakistan Economic Survey 2009-10 (Government of Pakistan, Ministry of Finance (2010)).

Yazdanie and Rutherford (2010) criticize the central structure of power generation sectors. In Pakistan, 66% of the total electricity is produced from expensive thermal sources using 42.8% oil and 28.12% gas of the gross domestic consumption. Whereas, the United States produces 50% from coal, 25% from natural gas and rest 25% from mixed source (Younos et al. (2009)). Scholars suggested different solutions to overcome electricity shortage. For instance, Yazdanie and Rutherford (2010) advocated to expand renewable power generation capacity. Jamil and Ahmad (2010) emphasized to develop hydel power production capacity. However, Amer and Daim (2011) conclude that there is no single ideal solution that meets national energy demand. A country needs a combination of suitable alternative technologies to ensure nationwide energy security.

Government strategies to tackle electricity shortfall by introducing breakdowns (load shedding) and increasing electricity prices are criticized by many scholars because these power-cuts not only exacerbate power availability situation but also play a vital role to determine future electricity prices for both domestic and industrial users. For instance, in 2008, when Pakistan was confronting the worst power shortfall, the government announced an increase of 62% and 71% in electricity prices for domestic and indusial users, respectively (Hasan et al. (2012)). Meanwhile, KESC was not willing to produce electricity from furnace oil due to its financial crisis. In the following years, both power shortfalls and electricity demand stretched a great deal. By the end of 2010, daily electricity demand outnumbers 20,000 MW with an average shortfall 2000 MW - 4000 MW (Haq and Hussain (2008)). Consequently, a considerable number of small and medium scale production units shut down due to high energy costs and frequent power shortfalls.

The most prominent feature of energy consumption in Pakistan is the household sector being the largest electricity consumer. The household sector alone represents more than 46% of the total electricity consumption, while, only 28% energy is used by the industrial sector (Nasir et al. (2008)). In contrast, in developed countries, 15% to 20% energy is consumed by the household (Dzioubinski and Chipman (1990)). They indicate that per capita household energy consumption in North America was much higher in early 1970's which eventually decreased over time. In contrast, Pakistan is following the other way around where the usage of energy efficient electronic appliances are not so common.

2.2 Electricity sector of Pakistan

Electricity in Pakistan is generated, transmitted and distributed by two vertically integrated semi-public and semi-private entities: Water and Power Development Authority (WAPDA) and KESC. WAPDA supplies electricity for all of Pakistan (except Karachi), whereas, KESC covers the City of Karachi and its surrounding areas. Competition in power generation sectors was introduced in late 1990, and since then there have been 27 independent power producers (IPPs) contributing significantly in national energy supply. Pakistan follows the single-buyer model of electricity supply where Pakistan Electric Power Company (PEPCO) produces thermal power as well as buys electricity from several producers including IPPs and Pakistan Atomic Energy Commission. A majority of IPPs generate thermal power from natural gas and petroleum products. IPPs buy inputs from national oil and gas companies, and frequent disruptions in cash flow cause unstable electricity supply.

At the time of independence in 1947, Pakistan inherited 60MW power generation ability to cater for the need of the whole population. However, with the acquisition of KESC in 1952 and the establishment of WAPDA in 1958, Pakistan's power sectors flourished rapidly. Despite the fast growth of the energy sector, energy demand has been outpacing aggregate supply due to rapid industrialization, urbanization, population growth and so on. Electricity supply has lagged behind demand since early 1980s. The power sector of Pakistan was unable to maintain required capacity due to poor governance, institutional weakness, unsuitable tariff structures and poor load management tactics to manage power shortfalls. Today, only 65% of the total population is getting electricity from the main grid and receiving unreliable and highly disruptive electricity.

2.3 Oil and gas sector of Pakistan

The GOP holds a significant stake in oil and gas sector as an owner, a manager, a policy maker and a regulator. Oil and gas are key components of Pakistan's energy meeting over 78% energy needs. While confronting global oil price shocks, Pakistan's oil related policies have been focusing on minimizing heavy dependence on oil imports. Despite these efforts, the country experienced massive oil supply disruptions during several occasions in the past including Iranian boycott 1951-53, Suez Crisis 1956, War of 1967, Ramadan War 1973, Iranian revolution 1979, Iran-Iraq war 1980, Gulf crisis 1991 and worldwide economic crises of 2008.

With its well-developed infrastructure, Pakistan is among the major consumers of natural gas in the region. It has sophisticated transportation, distribution and utilization systems of natural gas with 9,480 km transmission and 104,499 km of distribution network. There are two semi-state owned gas transmission and distribution companies namely: Sui-Northern Gas Pipelines and Sui-Southern Gas Company. With more than 3,000 compressed natural gas (CNG) stations, Pakistan is, as well, the world's largest CNG consumer. Pakistan does not import or export electricity and gas. Oil is only the traded form of energy. However, for future, the two most significant regional gas pipeline projects namely: Iran-Pakistan gas pipeline project and Turkmenistan-Afghanistan-India-Pakistan gas pipeline are in being planned.

3 Methodology

This study examines energy shortage through developing a unique index, ECI_t as a dependent variable, whereas we use energy prices, real income and other supply side factors as explanatory variables. Equation (1) is a mathematical representation of ECI_t for national, industrial and household levels.[5]

$$ECI_t = \frac{\text{Oil Consumption}_t + \text{Gas Consumption}_t}{\text{Electricity Consumption}_t} \tag{1}$$

[5] As mentioned earlier, in the agricultural sector, gas consumption is a null value.

To calculate ECI_t, all types of energy measurements are converted into a single unit (i.e., tonne of oil equivalent, TOE). It is plausible to assume that constant movements or smooth growth of the index without much fluctuations over time reflects the ideal situation of no power shortage because it implies that consumptions for all the types of energy follow some steady patterns. However, note again that a fluctuation of the index is considered the indicator of electricity substitution with oil and gas. Especially, in the context of Pakistan, people use backup generators of oil or gas for private electricity and thus, an increase in the index is an indicator of energy shortage when the occurrence of blackouts becomes more frequent. Therefore, by taking ECI_t as a dependent variable, we can analyze which factor significantly affects energy or electricity shortage.

In summary, ECI_t is assumed as a function of aggregate as well as sector-wise electricity prices (EP_t), oil price (OP_t), real gross domestic product per capita (GDP_t), electricity production ratio from thermal and non-thermal resources ($TNTPR_t$), and capacity utilized for power production (CU_t). Following the specification, we present the co-integrating equation used in this study:

$$ECI_t = \beta_0 + \beta_1 EP_t + \beta_2 OP_t + \beta_3 GDP_t + \beta_4 GDP_t^2 + \beta_5 TNTPR_t + \beta_6 CU_t + e_t \qquad (2)$$

where $TNTPR_t$ and CU_t are obtained from the following equations:

$$TNTPR_t = \frac{\text{Thermal Electricity Production}_t}{\text{Hydel Production}_t + \text{Nuclear Production}_t} \qquad (3)$$

$$CU_t = \frac{\text{Actual production}_t}{\text{Total installed capacity}_t} * 100. \qquad (4)$$

Based on economic theory, holding other factors constant, an increase in OP_t, GDP_t, and CU_t should have a negative association with the ECI_t, whereas EP_t is hypothesized to be positively associated. The coefficient of $TNTPR_t$ should give some important implication or a precise interpretation in the context of Pakistan's energy demand. In fact, it is known that installed capacity to produce electricity from hydel and nuclear sources is stable in short run and medium run. However, thermal energy production changes a great deal even overtime. Therefore, a fluctuation of $TNTPR_T$ is mainly driven by the change in thermal energy production.

When the coefficient of $TNTPR_t$ would be inversely correlated with ECI_t being negative, it implies that public thermal electricity production contributes to the reduction of oil and gas consumption for private electricity. If it is positively associated with ECI_t, public thermal electricity generation induces more consumption of oil and gas than electricity consumption under the same energy measurement unit (TOE). It means that the existence of public thermal plants for electricity generation in Pakistan cannot be justified from an energy efficient point of view, which should be an interesting policy question.[6]

Our analysis follows the two steps Engle and Granger procedure (Engle and Granger (1987)). In co-integration tests, all variables should be non-stationary or follow a random walk process for the co-integration regression to be meaningful. To identify the order of integration, we pretest stationarity of the variables with Augmented Dickey Fuller test with Schwarz Information Criterion (SIC) and double checked the results with Akaike Information Criterion (AIC) (Dickey and Fuller (1981)). In order to verify the results, we also employ the Phillips-Perron (PP) unit root test. Trend and intercept terms were used in these tests to control drift and/or trend in the data. From unit root results, if non-stationary time series are co-integrated at the same level, we can formulate an error correction model.

The estimation of error correction model gives useful inferences in short-run relationship among variables. Existence of co-integration relation among the variables can be tested by the unit root test of the residual term represented by the following equation:

$$\Delta \hat{e}_t = \alpha \hat{e}_{t-1} + \sum_{i=0}^{n} \delta_i \Delta \hat{e}_{t-i} + u_t \tag{5}$$

where Δ is the difference operator, $\hat{e}_t$ is the residual from equation (5), $n \geq 0$ is the number

[6] We did not include gas price as an explanatory variable in our model mainly due to the fact that gas price and oil price co-move in Pakistan. In other words, these fuel types are perfect substitutes and their prices always move in alike directions. The other reason for not including gas price as a covariate was unavailability of the data for the study period.

lags which make-up residual of equation, α and δ are the parameters to be estimated. A failure to reject the hypothesis, that $\hat{\alpha} = 0$, is evidence that the error term is not co-integrated. In such a case, results of simple OLS to estimate equation (1) do not lead to spurious regression and the OLS parameters are consistent.

In our co-integration model, the long-run relationships are summarized and interpreted by the following parameters

$$\frac{\partial ECI_t}{\partial EP_t} = \beta_1,\ \frac{\partial ECI_t}{\partial OP_t} = \beta_2,\ \frac{\partial ECI_t}{\partial GDP_t} = \beta_3 + \beta_4 GDP_t,\ \frac{\partial ECI_t}{\partial TNTPR_t} = \beta_5,\ \frac{\partial ECI_t}{\partial CU_t} = \beta_6.$$

Note that β_1 and β_2 capture the effect of electricity price and oil price on the dependent variable. The first order partial derivative of equation (1) with respect to GDP_t will help in identifying a possible non-linear effect as well as the associated turning level of real income for ECI_t if it exists. β_5 and β_6 show the relative effect of thermal and non-thermal electricity generation and the percentage of capacity utilized for electricity generation respectively.

Finally, the associated error correction model of the co-integrated relation can be estimated by

$$\begin{aligned}\Delta ECI_t = \alpha_0 + \alpha_1 \Delta EP_t + \alpha_2 \Delta OP_t + \alpha_3 \Delta GDP_t + \alpha_4 \Delta GDP_t^2 \\ + \alpha_5 \Delta TNTPR_t + \alpha_6 \Delta CU_t + \alpha_7 \hat{e}_{t-1} + \varepsilon_t.\end{aligned} \tag{6}$$

A first difference of each variable in equation (6) makes $I(1)$ integrated variables stationary. The relationship among stationary variables can be estimated to establish short-run effects among variables, which is one of the main objectives of an error correction model. Therefore, the coefficients of equation (6) are the estimates of short-run effects of each corresponding independent variables. In addition, the coefficient of error correction terms, α, is said to be the speed of adjustment for any shock leading to deviation from the equilibrium in the long-run. It is intriguing to note that sign and significance level of error correction term is evidence of long-run equilibrium relationship among variables in equation (6).

3.1 Data

We have used the data corresponding to annual observation from 1971 to 2010. The data have been gathered from several sources: electricity consumption (measured in GWh) for aggregate level and key sectors namely: industrial, household and agricultural levels and corresponding average prices for each category (in PKR/Kwh) are taken from Power System Statistics 2010 (Publication of WAPDA). Different prices paid by different sectors are necessary because of: i) the usual cross-sector subsidization ii) electricity prices are administered by the government in Pakistan rather than market determined. The data for oil consumption (in Tons), Gas consumption (measured in million cubic feet), oil prices (in PKR/liter), and electric power supply side series (such as electricity production from different sources (such as hydel, thermal and nuclear), total electricity production and actual installed capacity) are obtained from Ministry of Petroleum and Natural Resources and Hydrocarbon Development Institute of Pakistan (HDIP). Finally, real GDP per capita data, for national and sectorial levels, are collected from the World Bank.

4 Results and Discussion

This section provides the long-run and short-run dynamics of electricity fluctuations and the corresponding estimation results for a sample data of Pakistan for the period 1971 - 2010. Figure 1 consisting of four subfigures shows time series plots of ECI_t. Each subfigure corresponds to national, industrial, household and agricultural sectors, respectively. From this figure, we can see a general tendency that ECI_t declines over time except in the industrial sector. At the same time, we notice a high volatility of ECI_t for energy intensive sectors, i.e., industrial and agricultural sectors . Especially, for the industrial sector, ECI_t fluctuates and do not necessarily decline over time. This implies that oil and gas have been heavily used for backup generators by this sector in response to electricity shortage.

Next, figure 2 shows the trends of all the time series data used for this study as explanatory variables. As can be seen, the variables of EP_t, OP_t and GDP_t exhibit the same qualitative feature of time series plots, irrespective of sectors, that is, an upward time trend. On the other hand, it must be noticed that important supply side variables of CU_t and $TNTPR_t$ exhibit some degree of fluctuations over time. This exemplifies some problems Pakistan has faced in electricity generation up to now. That is, capacity utilization and thermal power generation has not been so stable in Pakistan, which has signified energy shortage.

Before going into further analysis, we first examine the order of stationarity. In order to obtain the exact level of integration, we employ Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. Table 4 shows the results of both Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. The results imply that all the variables are integrated in order one $I(1)$. These results are consistent with the requirement for the rest of time series analysis. That is, individual variables are stationary at their first differences. Hence, co-integration models are estimated with level variables and ECMs with first differences data.

Table 5 shows a long-run association of ECI_t with electricity and oil prices, real income, thermal & non-thermal power production ratio and percentage of capacity utilized for electric power production. In co-integration results for aggregate, industrial and household level regressions, most of the variables are significantly different from zero and sings of the coefficients are in alignment with the economic theory and hypothesis of this study. An exception is the result for the agricultural sector, which will be discussed later.

In a long-run equation, electricity price is positively correlated with ECI_t. This might be due to a decrease in electricity consumption and/or increase in oil and gas consumption as substitutes. Significant coefficients of EP_t for the national and industrial sectors refer to the fact that these sectors are highly responsive to electricity prices compared to the household sector. These results are consistent with Khan and Ahmed (2009) and Chaudhry (2010) with clear implications that the electricity is the primary source of energy for poor households in Pakistan. Increasing electricity prices may harm standards of living by deepening poverty. Finally, the coefficient of EP_t for agriculture sector is insignificant, whose cause will be discussed later.

$TNTPR_t$ consistently shows negative signs for national, industrial and agricultural sectors, two of which is statistically significant. This result implies some useful policy implications. To understand these implications, it is essential to recall that power generation from non-thermal sources (e.g. nuclear and hydel) remains steady in Pakistan. The major change in the variable of $TNTPR_t$ comes from the expansion or shrinkage of thermal power production. Negative and significant signs of the coefficients suggest that public thermal power production for electricity can reduce the use of gas and oil for private purpurses, i.e., a reduction of ECI. In other words, an increase in electricity supply from public thermal power plants definitely reduces overall consumptions of gas and oil even for private electricity. This is more desirable because public electricity generation through power plants is more energy-efficient than privately generated electricity from backup generators.

This result further suggests some possible governmental regulation for the future. That is, private electricity production using backup generators should be regulated by the government from an energy efficiency perspective, so that the inputs of oil and gas for backup generators could be diverted to public power production. This result is consistent with policy recomme-dations made by Steinbuks and Foster (2010) that privately generated electricity using backup generators is very expensive and energy-inefficient due to lower fuel efficiency, compared to government thermal power stations. These authors claim that such private electricity generation must be regulated from a social planner's point of view.

Concerning utilization of installed capacity for electricity production, our result confirms that the underutilization of this capacity is one of the major reasons for electricity shortfalls. Negative and significant coefficients of CU_t for national, industrial and household sectors explain higher capacity utilization will reduce ECI_t to make the country better off. As a matter of fact, Pakistan has been exploiting the total power generation capacity in the range of 37% to 57% as shown in Figure 2 (in the subgraph of CU) and Table 3. In 2010, only 39% of 22,263 MW installed capacity was utilized whereas the worst power shortfall in 2011 peaked at 6000 MW which makes 27% of total capacity (PEPCO, National & Despatch CO (NTDC) (2010)). Management could overcome this shortage by utilizing 66% of this capacity. This result supports the finding of Jamil and Ahmad (2010) that the policies to utilized optimum power generation capacity should be prioritize over policies for expanding the capacity.

Finally, negative and significant coefficients of GDP_t refer to the fact that electricity consumption increase more than the combined income and oil and gas with increase in real income. Household sector is about four times more responsive to this change compared to national and industrial sectors. This relationship seems plausible because higher income leads to the purchase of more electronic goods which facilitate the further use of electricity. However, note also that GDP_t^2 exhibit significant non-linear association with ECI_t with the positive sign. This means the relative electricity consumption increases faster than the combined consumption of oil and gas in GDP_t when GDP_t is not so high, holding other factors constant. However, this effect becomes reversed once GDP_t becomes sufficiently high.

To illustrate this type of non-linear effects from the regression results, we use the regression result in the national sector. The turning point in the national sector is identified as $GDP^* =$ USD 1127 indicating the threshold value below which GDP_t is negatively associated with a national ECI_t and above which GDP_t is positively associated with a national ECI_t. More specifically, this result implies that if Pakistan does not improve the supply side of power generation such as CU_t or $TNTPR_t$, demand for oil and gas will outnumber the demand for electricity as GDP_t exceeds the threshold value of the turning point. This is because people will be using these inputs to meet electricity demand using backup generators. This result is another confirmation for the findings of Hasan et al. (2012) in that there is huge and significant energy shortfall in the Pakistan without improvement of power supply systems.

Based on International Monetary Fund (2012), the real GDP of Pakistan is projected to grow over 3.5% annually for next five years. At the given growth rate, real GDP per capita will reach the threshold value of USD $1,127$ within the next ten years. It is, therefore, necessary for the planner to take timely measures to ensure sustainable and stable electric supply. Otherwise, Pakistan is already on the verge of national level energy insecurity stage, which is illustrated by this non-linear estimation result estimated in our study.

For agriculture sector, although some of the signs are as expected, yet none of the variables are significant. There could be two main reasons that our model did not fit agricultural sector:

i) agricultural sector does not consume natural gas, and ii) Our model did not control key determinant of energy demand in agricultural sector of Pakistan. For instance, a number of environmental factors (such as cyclic floods, droughts, average annual rainfall), geographical factor (such as elevation, tilt of land) and mode of cultivation (such as arid, semi-arid or irrigated) play vital roles to determine energy consumption of agricultural sector in Pakistan. An exclusive study to model energy consumption dynamics of agricultural sector would be necessary for the future research.

Table 6 represents the results of ECMs for short-run dynamics. These results contain error correction terms obtained from the lagged value of stochastic error terms of co-integration equations. Negative and significant co-efficient of error correct terms confirm the existence of equilibrium in long-run, and their magnitudes represent the velocity of adjustment. Overall, the effect of significant variables is lower in short run than that in long run. According to the results, price shocks do not affect energy consumption in short run for any category. In fact, price changes do not affect energy demand spontaneously, which is in line with the real-world observation and experience. However, end-consumers adjust consumption level in the following period. Per capita real income, $TNTPR$ and CU affect energy consumption for national level in the same manner as in long-run. However, GDP and CU become insignificant in short-run for industrial and household level respectively.

One point to mention is that high significance of $TNTPR$ variable in both long-run and short-run. This result suggests the importance of thermal power production at national level. Likewise, significance of optimal electricity generation from installed capacity is confirmed from the results associated with CU. These results are in line with economic intuitions and illustrate that improvement of supply side in electricity generation is highly linked to ECI_t in short-run and long-run perspectives.

5 Conclusion

This study has investigated the interrelationship between energy consumption, prices, real income, effects of power generation from different sources and utilization of total installed capacity for power production by using co-integration and error correction models. We examined annual data for national level as well as for major sectors of the economy namely: industrial, household, and agricultural for the period 1971 - 2010. Our main findings are as follows: first, end-consumers adjust their energy demand to the prices only in long-run. Second, under-utilization of installed power generation capacity encourages fossil fuel consumption for private electricity. Third, uninterrupted electricity supply could be attained through regulating private electricity generation. Fourth, the relative demand for electricity increases and then decreases with real income in relation to gas and oil.

Overall, our investigation implies that price adjustments tactics adopted by the government are not effective policies to deal with power shortage if oriented to short-run impacts. Rather, the government should focus on improving utilization rate of installed power plants and re-channeling the use of oil and gas for public electricity generation. Otherwise, energy shortage shall be worsened with economic growth in Pakistan, and the economy will suffers from welfare loss. During recent decade, energy policy of Pakistan focused on expanding production capacity through placing rental power plants to address electricity shortage. Present study suggests that policies for the optimal utilization of existing electricity generation capacity should be prioritized rather than installing new power plants. The government should also make the best utilization of scarce natural gas and expensive oil resources as well as install capacity of power plants.

Finally, we acknowledge some limitation of this study. First, our model does not fit for agricultural sector due to the possibility of having several missing factors determining agricultural energy consumption such as environmental, climatic conditions, different modes of irrigation, geographical characteristics and so on. Future studies to investigate power shortage dynamic in agricultural sector by incorporating such important factors must be addressed in the future research.

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Figure 1: Aggregate and sector-wise plots of ECI_t for the period, 1971 - 2010

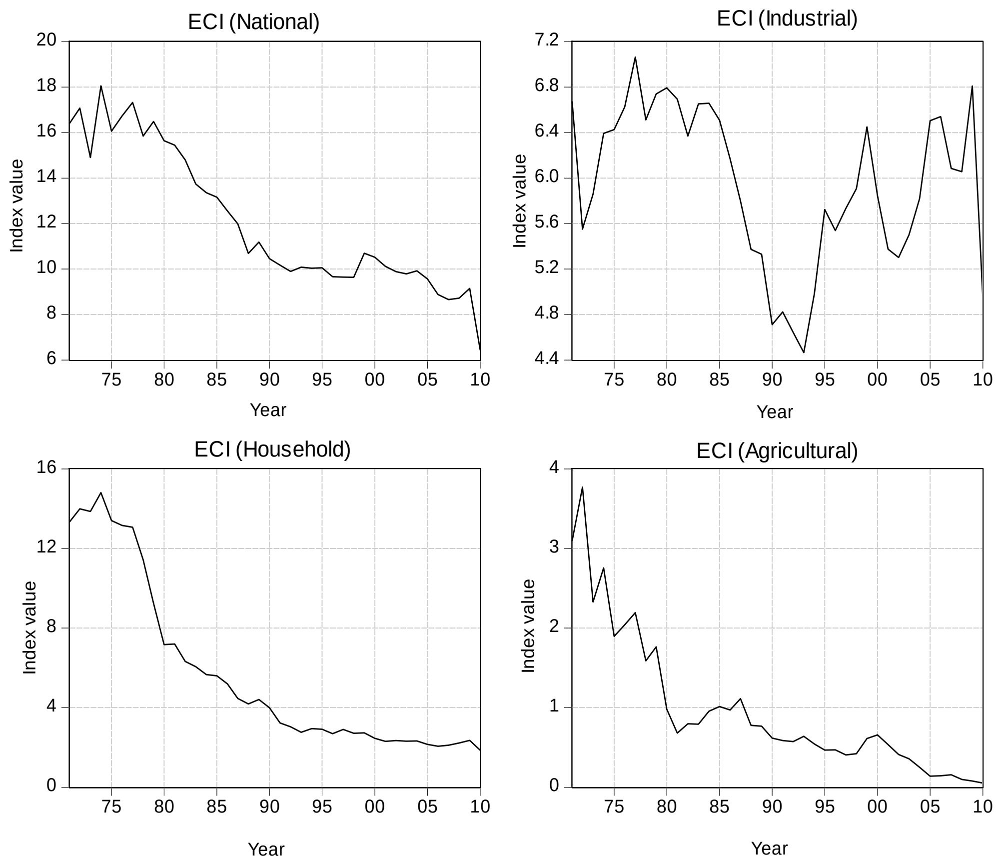

Figure 2: Trends of relevant variables for the period, 1971 - 2010.

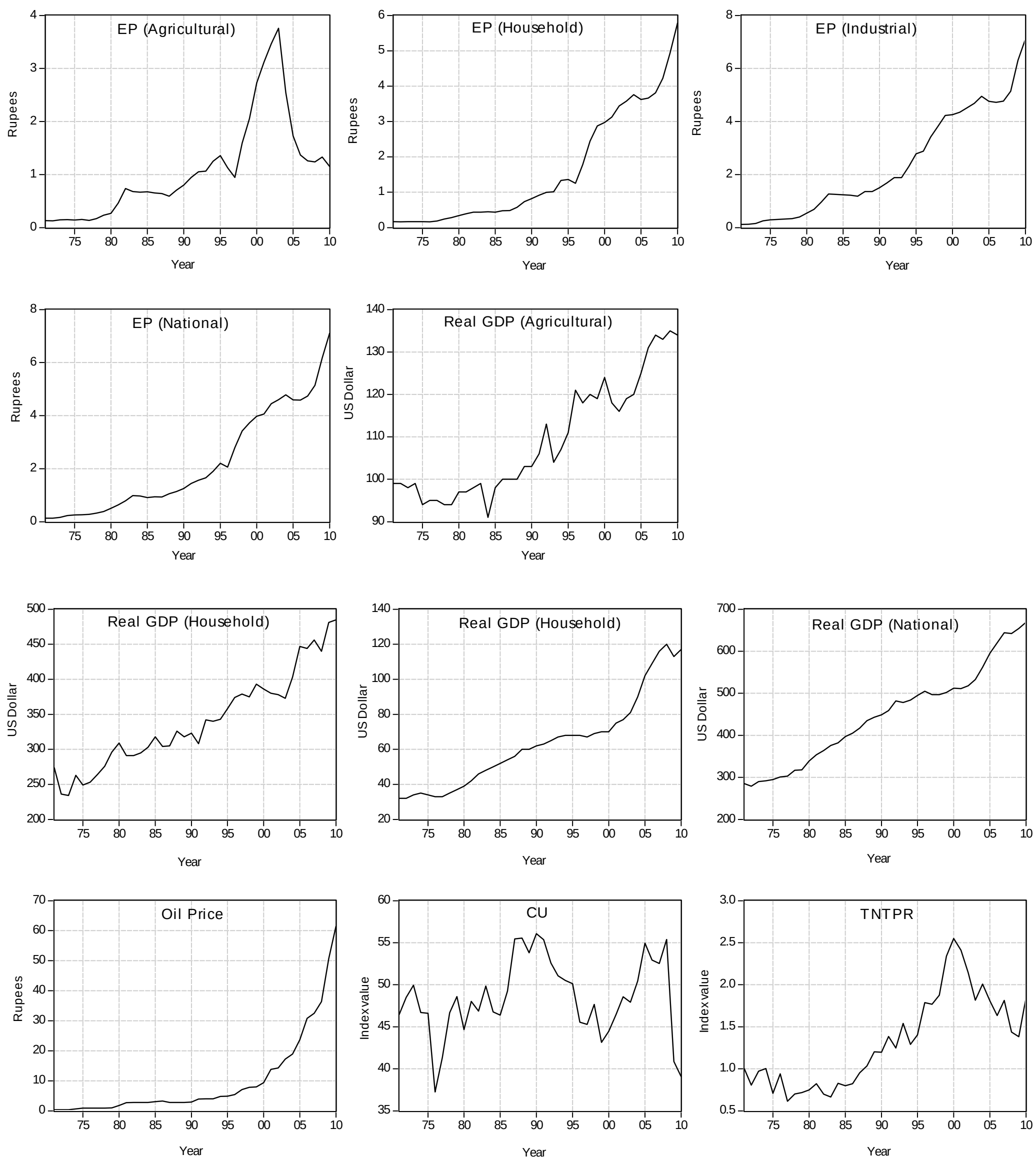

Table 1: Primary energy supply and per capita availability

Year	Energy supply		Per capita	
	Million TOE	Change (%)	Availability (TOE)	Change (%)
1998	41.72	-	0.31	-
1999	43.19	3.51	0.32	1.28
2000	44.4	2.82	0.32	0.36
2001	45.07	1.5	0.32	-1.25
2002	47.06	4.41	0.32	2.86
2003	50.85	8.06	0.34	5.25
2004	55.58	9.26	0.36	6.45
2005	58.06	4.18	0.37	2.48
2006	60.62	4.33	0.38	2.61
2007	62.92	3.78	0.39	2.86
2008	62.55	-0.58	0.38	-2.27
2009	47.1	-	0.29	-
2010	46.8	-0.64	0.28	-3.09

Source: Hydrocarbon Development Institute of Pakistan (HDIP), published in Economic Survey of Pakistan 2009-10.

Table 2: Percent change in primary energy supply

Year	Electricity		Gas		Petroleum Products	
	(Gwh)	Change (%)	(mmcft)	Change (%)	Tonnes (000)	Change (%)
2007	73,400.00	0.90	1,275,212.00	4.40	18,080.00	7.30
2008	70,371.00	-4.10	1,269,433.00	-0.50	17,911.00	-0.90
2009	55,614.00	-	931,700.00	-	12,892.00	-
2010	54,653.00	-1.70	959,475.00	3.00	13,937.00	8.10

Source: Hydrocarbon Development Institute of Pakistan (HDIP), published in the Economic Survey of Pakistan 2009-10.

Table 3: Electricity generation and consumption in Pakistan

	Generation			Consumption	
Year	**Installed Capacity (MW)**	**Total Generation (GW/h)**	**Capacity Utilized (Percentage)**	**Total Cons. (MW/h)**	**Percentage of total generated consumed**
1971	1,862	7,572	46.42	3,966	52.38
1976	2,528	10,319	46.60	5,315	51.51
1981	4,205	17,688	48.02	9,068	51.27
1986	6,653	28,703	49.25	15,504	54.02
1991	9,369	45,440	55.37	26,585	58.51
1996	14,818	59,125	45.55	36,925	62.45
2001	17,789	72,406	46.46	43,384	59.92
2006	19,439	90,125	52.93	62,405	69.24
2010	19,650	67,239	39.06	54,653.0	81.28

Source: PEPCO, National & Despatch CO (NTDC) (2010).

Table 4: Results of unit root test.

Variable/Sector	ADF		Philips-Perron (PP)		Order of integration
	Levels	First difference	Levels	First difference	
National					
ECI	-0.61	-11.27***	-0.13	-11.05***	I(1)
GDP	0.72	-4.59***	1.28	-4.59***	I(1)
EP	-0.4	-3.23*	0.40	-3.27*	I(1)
Industrial					
ECI	-2.31	-6.09***	-2.32	-6.08***	I(1)
EP	1.42	-2.73*	2.26	-2.73*	I(1)
GDP	0.61	-3.79***	1.03	-3.85***	I(1)
Household					
ECI	-2.34	-2.98**	-1.73	-4.51***	I(1)
EP	-0.17	-3.44*	-1.28	-4.50***	I(1)
GDP	0.45	-7.81***	2.39	-9.82***	I(1)
Agriculture					
ECI	-1.08	-11.91***	-2.83	-10.33***	I(1)
EP	-2.1	-3.40**	-1.61	-3.48**	I(1)
GDP	-0.04	-7.55***	0.66	-7.86***	I(1)
Other variables					
OP	0.28	-4.88***	0.32	-4.76***	I(1)
TNTPR	-1.08	-6.81***	-1.02	-6.81***	I(1)
CU	-2.46	-6.56***	-2.46	-6.59***	I(1)

Note: ***, ** and * indicate the level of significance at 1%, 5% and 10% respectively.

Table 5: Results of co-integration regressions

Dependent Variable, ECI	Coefficients			
Variable	**National**	**Industrial**	**Household**	**Agricultural**
Constant	43.911***	13.698***	92.265***	13.477
EP	1.073***	0.946***	1.071	-0.349
OP	-0.155***	-0.117***	-0.208**	-0.017
GDP	-0.106***	-0.141***	-0.429***	-0.167
GDPSQ	0.0001***	0.001***	0.0006***	0.001
TNTPR	-1.820***	-1.517***	-1.241	0.299
CU	-0.057*	-0.054*	-0.125**	-0.039
R^2	0.957	0.629	0.923	0.547
Adjusted R^2	0.949	0.562	0.909	0.465
Durbin-Watson Statistics	1.88	1.402	1.736	0.482
t-statistics of residual in the unit root test	-5.877***	-4.568***	-6.823***	-3.117**

Note: ***, ** and * indicate the level of significance at 1%, 5% and 10% respectively.

Table 6: An error correction model

Dependent Variable, ΔECI	Coefficients			
Variable	**National**	**Industrial**	**Household**	**Agricultural**
Constant	0.085	-0.078	-0.286**	-0.0043
ΔEP	-0.163	0.044	0.626	-0.076
ΔOP	-0.069	-0.045	-0.051	-0.537
ΔGDP	-0.086*	0.077	-0.103***	-0.005
ΔGDPSQ	0.0001	-0.0001	0.0001***	0.00002
ΔTNTPR	-1.813***	-0.997***	-1.034**	-0.225
ΔCU	-0.063*	-0.060***	-0.045	-0.020
$\hat{e}_{t-1}$	-1.056***	-0.794***	-0.386***	-0.253**
R^2	0.631	0.588	0.37	0.243
Adjusted R^2	0.548	0.495	0.228	0.073
Durbin-Watson Statistics	2.075	1.579	1.782	2.842

Note: ***, ** and * indicate the level of significance at 1%, 5% and 10% respectively.