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Article

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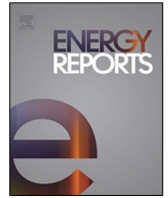
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Research paper

Dilemma of direct rebound effect and climate change on residential electricity consumption in Pakistan

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ABSTRACT

Energy efficiency improvements owing to technological progress in the energy-using appliances and equipment lower effective price of energy services and, in turn, result into behavioural ex-post increase in the consumption of energy. Thus, on net basis technological progress negatively influences the effectiveness of energy efficiency and circumvent the effects of environmental sustainable policies. This study is the first of its nature in Pakistan that estimates the magnitude of *direct rebound effect* in residential electricity consumption. Using the time series data from 1973 to 2016, we apply co-integration econometric technique and error correction model to analyse the direct rebound effect. The results indicate that the magnitude of direct rebound effect is 69.5 percent in the long run, while 42.9 percent in the short run. Further, impact of climate change on electricity consumption is examined. The results indicate that consumption of energy is increasing in both short run and long run under climatic changes. These findings suggest that the Government of Pakistan needs to consider rebound effects along with climatic changes in formalizing its energy policies.

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1. Introduction

Since the emergence of oil price shock in 1973, the world has put its efforts to develop energy efficient technology to reduce energy consumption and decreasing reliance on most expensive source of energy, that is, crude oil. It also had damaging effects for the macroeconomic performance of oil importing countries. Global acceptance of access to affordable, reliable, sustainable and modern energy for all as one of the Sustainable Development Goals can be presented as a case. However, with the decrease in per unit price of energy service, due to improvements in energy efficiency, there are chances of demand of energy not decreasing by the same proportion due to extra energy consumption. It was first pointed out by William Stanley Jevons in the 19th century. He argued that improvements in energy efficiency of steam engines in United Kingdom cannot decrease the coal consumption. The roots of this argument lie in consumer theory. The energy efficiency improvements lead to change in relative prices of various available energy services and increase in the real income of consumer. Therefore, due to the involvement of substitution and income effects after

the improvement of energy efficiency, energy consumption may not decrease with the same proportion, which is termed as *energy rebound effect* in the energy literature. It thus calls for need to capture the energy rebound effect for effective policy making.

Reducing carbon emissions and energy consumption are primary concerns for most governments and energy policymakers around the globe. In this context, intensive efforts have been intended towards evolving sustainable use of energy that is coherent with climate change mitigation and energy security. Promotion of energy efficiency is most adopted policy approach or option to achieve these objectives. Programme launched by the government of Pakistan as Tranche-I is such an example to reduce electricity consumption at household level. However, energy consumption has grown rapidly and continuously in Pakistan despite taking policy initiatives to stimulate energy efficiency. Potentially, energy efficiency improvements from technological progress in the energy-using appliances and equipment lower effective price of energy services and behavioural ex-post increase in the consumption of energy (Sorrell, 2007). Thus, on net basis technological progress negatively influences the effectiveness of energy efficiency and environment sustainable policies.

The case of Pakistan is also interesting due to ambiguous tariff structure and heavy provision of subsidies to the energy consumers, and demand supply gap as its structural facts. Furthermore, rebound effect and climate change effect are not considered

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in forecasting energy demand and policy making that leads to unsustainable environment and energy. The importance of energy rebound effect have highlighted by Saunders (2000), Bentzen (2004), Sorrell et al. (2009), Saunders (2016), Sorrell (2014) and Wei (2007). The magnitude of rebound effect in household sector is extensively studied by Wang et al. (2014), Zhang and Peng (2016), Fox and Hara (2012), Chitnis and Sorrell (2015), Wang et al. (2016), Peters and Mcwhinnie (2015) and Chitnis et al. (2013). These studies identify the short run and long run magnitudes of rebound effect in household sector. However, the literature is deficient on investigating the energy rebound effect in household electricity consumption in Pakistan. Therefore, this study aims to examine the magnitude of direct rebound effect and the impact of climate change on residential electricity consumption in Pakistan. Using the time series data from 1973 to 2016, we apply co-integration econometric technique and error correction model to analyse the direct rebound effect.

This study is organized as follow: Section 2 presents the methodology on direct rebound effect, energy prices and energy consumption, and role of climate change in energy consumption. Section 3 discusses the empirical model. Section 4 analyses the results, and Section 5 concludes and gives policy suggestions.

2. Methodology and data

2.1. Direct rebound effect, energy prices and energy consumption

Energy rebound effect defines the relationship between energy consumption and energy efficiency. It is based on the theory of utility. The main cause of energy rebound effect is an improvement in energy efficiency that primes to a decrease in the cost of energy services, which ex-post increase the consumption of energy. The service cost of energy can be expressed as

$$P_s = \frac{P_E}{e} \quad (1)$$

where, P_E is price of energy, such as cost of electricity per unit. P_s is price of energy service and e is energy efficiency or useful energy service provided that $e = \frac{S}{E}$, such as S represents an energy service (e.g. lighting, space heating or cooling), E denotes the energy demand that provides energy service. Eq. (1) is indicating that increase in energy efficiency decreases the real cost of energy service (P_s).

By following (Saunders, 2000), the change in energy consumption due to energy efficiency is defined as elasticity of fuel use or energy conservation, which is as follow:

$$\eta_e = \frac{d \ln E}{d \ln e} \quad (2)$$

where, η_e is the efficiency elasticity of energy use. The rebound effect (RE) is defined as

$$RE = 1 + \eta_e \quad (3)$$

If $\eta_e = -1$ and so $RE = 0$ (no rebound), it is indicating one for one reduction, in other words 1 percent increase in energy efficiency causes to reduce energy consumption by 1 percent. If fuel is reduced by half of energy efficiency gain, $RE = 0.5$ (50% rebound effect), It is indicating that 1 percent increase in energy efficiency is reduced only by half of energy consumption instead of 1 percent. When $RE < 1$, it is called partial rebound effect. If $RE = 1$, it is called 100 percent or full rebound effect. It is indicating that 1 percent increase in energy efficiency has failed to reduce the consumption and people start consuming as more as they are saving from efficiency improvement. Backfire occurs when $RE > 1$ (greater than 100 percent Rebound effect), fuel use increases because of a fuel efficiency gain. Similarly, “super

conservation” happens when $RE < 0$, it indicates that one percent increase in energy efficiency reduces more than one percent of energy use.

It is difficult to calculate the energy efficiency (e), the energy rebound effect is often estimated from the price elasticity of energy consumption (Saunders, 2008; Sorrell, 2014). Many economists used price elasticity of energy consumption to calculate the energy rebound effect as follow:

$$RE = -\eta_{pe} \quad (4)$$

where, η_{pe} is the price elasticity of energy consumption. When we use the above method to estimate energy price elasticity, the premise is to decline in the price of energy. However, prices are fluctuating (Wang et al., 2014). To solve this problem, Dargay (1991) and Huntington and Gately (2002) decompose the price into maximum, rise and fall of energy prices. Bentzen (2004) indicated that coefficient of fall in price represents the rebound effect. Thus, price decomposition is defined as:

$$P_{E_{it}} = P_{E_{it}}^{max} P_{E_{it}}^{cut} P_{E_{it}}^{rec} \quad (5)$$

where, $P_{E_{it}}$ is the price of energy in the history, $P_{E_{it}}^{max}$ is the highest price in the history, $P_{E_{it}}^{cut}$ is price fall and $P_{E_{it}}^{rec}$ is price rise or recovery in the history. In which

$$\begin{aligned} P_{E_{it}}^{max} &= \max \{P_{E_{i1}}, P_{E_{i2}}, \dots, P_{E_{it}}\} \\ P_{E_{it}}^{cut} &= \prod_{m=0}^t \min \{1, ((P_{E_{im-1}}^{max} / P_{E_{im-1}}) / (P_{E_{im}}^{max} / P_{E_{im}}))\} \\ P_{E_{it}}^{rec} &= \prod_{m=0}^t \max \{1, ((P_{E_{im-1}}^{max} / P_{E_{im-1}}) / (P_{E_{im}}^{max} / P_{E_{im}}))\} \end{aligned} \quad (6)$$

For example, Fig. 1 depicts natural log of average residential electricity price in Pakistan from 1973 to 2016 and Fig. 2 depicts the decomposition of the average electricity price in Pakistan from 1973 to 2016. Taking the log of Eq. (5) yields:

$$\ln P_{E_{it}} = \ln P_{E_{it}}^{max} + \ln P_{E_{it}}^{cut} + \ln P_{E_{it}}^{rec} \quad (7)$$

2.2. Climate and energy consumption

Energy consumption variates in response to climatic change, the consumption of energy is increased in the cooling and heating days. Wang et al. (2014) calculated the heating degree days (HDD) and cooling degree days (CDD) as follow:

$$\begin{aligned} HDD &= \sum_{m=1}^{12} (1 - D) (T_{BHDD} - T_m) M \\ CDD &= \sum_{m=1}^{12} (D) (T_m - T_{BCDD}) M \end{aligned} \quad (8)$$

T_m is the average monthly temperature; T_{BHDD} represents base temperature of the heating degree day; T_{BCDD} , the base temperature of CDD; $D = 1$, if average monthly temperature is higher than the base; otherwise, $D = 0$. Jamil and Ahmad (2011) have taken 12° as base temperature of the heating degree day and 24° as base temperature of cooling degree day in case of Pakistan. The degree days' value in a year is calculated by adding HDD and CDD.

$$DD = HDD + CDD \quad (9)$$

2.3. Data sources

This study uses the data from 1973–2016 to examine the dilemma of direct rebound effect and climate change on residential electricity consumption in Pakistan. It takes residential electricity consumption and price data from National Transmission and

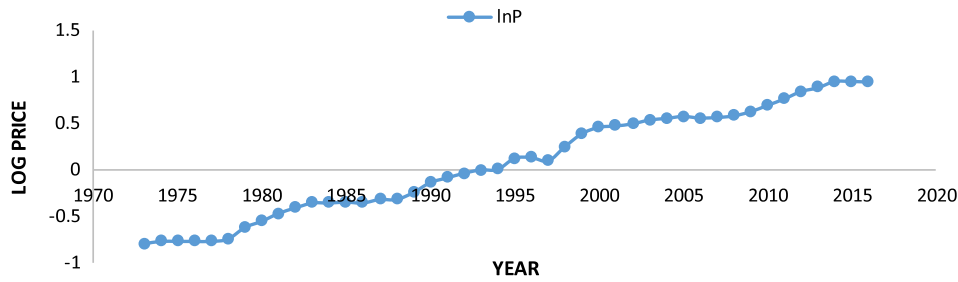


Fig. 1. Trend of log residential electricity prices.

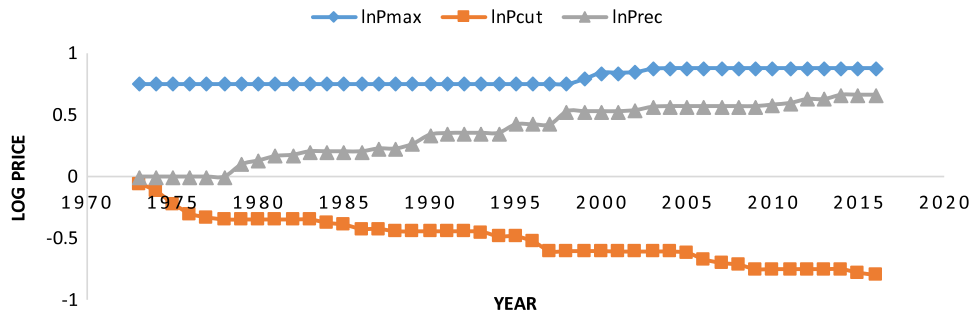


Fig. 2. Decomposition of log residential electricity prices.

Despatch Company (NTDC), Pakistan. The data of temperature to calculate the cooling degree days and heating degree days are obtained from Climate Change Knowledge Portal, World Bank. The data of population and per capital GDP are taken from World Development Indicator (WDI).

3. Empirical model

3.1. Error correction model

Electricity demand can be illustrated between long and short run demands. In the short run, there is no or less adjustment for electricity equipment purchasing, especially in the residential electricity consumption. Residential electricity has less substitutability and its price is inflexible. In the long run, consumers can adjust their consumption, either by changing their behaviours, as well as they can buy more efficient appliances in the future. In the long run price inclines to be elastic. Therefore, research on electricity demand is considered the short run and long run dynamics separately. To differentiate short run and long run price elasticity variations in residential electricity consumption, an error correction model (ECM) is better measure to evaluate direct rebound effect. ECM is used to estimate short run elasticities.

ECM is a precise econometrics model, which uses a long run co-integration equation as an instrument variable to solve the spurious regression problem. This study takes the short run price-cut elasticity as the short run energy rebound effect. The relationship between the residential electricity consumption (E_t) and explanatory variables, such as the decreasing electricity prices ($P_{E_t}^{cut}$), prices recovery ($P_{E_t}^{rec}$), price maximum ($P_{E_t}^{max}$), population growth (POP), heating degrees' days (HDD), cooling degrees' days (CDD) and per capital GDP ($PGDP$) is as follow

$$\ln E_t = \alpha + \beta_1 \ln P_{E_t}^{max} + \beta_2 \ln P_{E_t}^{cut} + \beta_3 \ln P_{E_t}^{rec} + \beta_4 \ln POP_t + \beta_5 \ln DD_t + \beta_6 \ln PGDP_t + u_t \quad (10)$$

According to the co-integration analysis, we shall establish that there is a long run equilibrium relationship between the dependent variable and explanatory variables. To offset the deficiency of the

long-term statistical model, we construct a short-term dynamic model to reflect the correction mechanism for the short run equation deviating from the long run. So, from Eq. (10), we can obtain the residual series as follows:

$$\hat{u}_t = ecm_t = \ln E_t - \alpha - \beta_1 \ln P_{E_t}^{max} - \beta_2 \ln P_{E_t}^{cut} - \beta_3 \ln P_{E_t}^{rec} - \beta_4 \ln POP_t - \beta_5 \ln DD_t - \beta_6 \ln PGDP_t \quad (11)$$

Eq. (11) is taken as error correction. Then the short-term estimations are obtained through ECM as follow:

$$\Delta \ln E_t = \gamma_1 \Delta \ln P_{E_t}^{max} + \gamma_2 \Delta \ln P_{E_t}^{cut} + \gamma_3 \Delta \ln P_{E_t}^{rec} + \gamma_4 \Delta \ln POP_t + \gamma_5 \Delta \ln DD_t + \gamma_6 \Delta \ln PGDP_t + \gamma ecm_{t-1} + \varepsilon_t \quad (12)$$

The negative value of the coefficient for price-cut parameter ($-\gamma_2$) is the magnitude of direct rebound effect. It is negative price elasticity of energy consumption/demand in the improvement of energy efficiency, ecm_{t-1} is the deviation from long term equilibrium in the previous period, ε_t is random error term and the series with differences is indicating the volatility of the variable.

4. Results and discussion

4.1. Unit roots

There are many methods for time series unit root test and each of them has its own uniqueness. In order to get precise results, this paper has used Augmented Dickey Fuller (ADF) and Phillips Perron (PP) unit root tests for each variable. The results of unit root test are shown in Table 1. Both tests indicate that all variables are integrated of order 1. The results from EG two step test method also suggest that a co-integration relationship exist among the variables.

4.2. Long run results

The co-integration results are shown in Table 2. The negative value of the estimated parameter coefficient for price-cut is indicating the magnitude of direct rebound effect in the long run, which is 69.5 percent. Whereas, the increasing degree days cause to

Table 1
Results of unit root test.

| Variable | Augmented Dickey Fuller test | Phillips Perron test |
|----------------------|------------------------------|----------------------|
| $\ln E$ | 0.034502 (0.6878) | 2.254851 (0.9933) |
| $\Delta \ln E$ | -4.513173 (0.0008) | -3.609769 (0.0006) |
| $\ln p^{max}$ | -1.119353 (0.6988) | -0.357105 (0.9073) |
| $\Delta \ln p^{max}$ | -1.869881 (0.0593) | -4.115770 (0.0024) |
| $\ln p^{cut}$ | 2.973159 (0.9990) | -2.368141 (0.1565) |
| $\Delta \ln p^{cut}$ | -3.859361 (0.0050) | -3.783007 (0.0061) |
| $\ln p^{rec}$ | -1.060200 (0.7228) | -1.078989 (0.7156) |
| $\Delta \ln p^{rec}$ | -6.473486 (0.0000) | -6.473553 (0.0000) |
| $\ln POP$ | 1.004990 (0.9140) | 0.119235 (0.9965) |
| $\Delta \ln POP$ | -4.345032 (0.0071) | -4.286916 (0.0081) |
| $\ln PGDP$ | -1.456670 (0.5457) | -1.359003 (0.5933) |
| $\Delta \ln PGDP$ | -5.433398 (0.0000) | -5.405213 (0.0001) |
| $\ln DD$ | -2.231395 (0.16050) | -2.233398 (0.17001) |
| $\Delta \ln DD$ | -6.331391 (0.0000) | -6.191399 (0.0000) |

Δ represent the first order difference. The value in the bracket represent *P*-value

Table 2
The results of long run co-integration equation.

| Variable | Coefficient | <i>t</i> -Statistics | Prob. |
|----------------------------|-------------|----------------------|--------|
| $\ln p^{max}$ | -0.708191 | -3.578260 | 0.0010 |
| $\ln p^{cut}$ | -0.695990 | -4.531351 | 0.0001 |
| $\ln p^{rec}$ | 0.210441 | 1.751940 | 0.0883 |
| $\ln POP$ | 0.499001 | 1.981891 | 0.0564 |
| $\ln PGDP$ | 0.058249 | 0.386365 | 0.7019 |
| $\ln DD$ | 0.298919 | 2.269315 | 0.0345 |
| <i>C</i> | 4.776373 | 8.939179 | 0.0000 |
| Adjusted <i>R</i> -squared | 0.978157 | | |
| Durbin Watson stat. | 1.746299 | | |
| <i>F</i> -statistics | 740.3367 | | |

increase the energy consumption. Results indicate that one percent increase in *DD* causes to increase 0.29 percent electricity consumption in the long run. The coefficient of population (*pop*) is 0.49, which indicates that one percent increase in population causes to increase 0.49 percent in the demand of residential electricity consumption. The coefficient of per capital GDP (*PGDP*) is positive but insignificant in the long run.

4.3. Short run results

The short run results are shown in Table 3. The negative value of the estimated parameter coefficient for price-cut indicates the magnitude of direct rebound effect in the short run, which is 42.9 percent. Whereas, the increasing degree days cause to increase the energy consumption in the short run. Result indicate that one percent increase in *DD* cause to increase 0.31 percent energy consumption. Growth of population and per-capital income also cause to increase the consumption of electricity in the short run. The coefficient of population is 0.29 indicating that one percent increase in population causes to increase 0.29 percent in electricity consumption in the short run. Similarly, the one percent increase in income per-capital causes to increase the 0.47 percent increase in the electricity consumption in residential electricity consumption in the short run. The coefficient of ecm_{t-1} is -0.48, which indicates that the speed of adjustment to reach the equilibrium at current period. It is negative and significant at 1 percent level.

5. Conclusion

The results indicate that the magnitude of direct rebound effect is 69.5 percent in the long run, while 42.9 percent in the short run. Further, impact of climate change on electricity consumption is examined by paying special attention of cooling degree days and heating degree days wherein both degree days increase the use of electricity consumption. Growing level of income and

Table 3
The results of error correction model.

| Variable | Coefficient | <i>t</i> -Statistics | Prob. |
|----------------------------|-------------|----------------------|--------|
| $\ln p^{max}$ | -0.886699 | -4.110515 | 0.0002 |
| $\ln p^{cut}$ | -0.429522 | -3.767862 | 0.0006 |
| $\ln p^{rec}$ | 0.298274 | 1.483679 | 0.1464 |
| $\ln POP$ | 0.298919 | 1.610003 | 0.1157 |
| $\ln PGDP$ | 0.472901 | 6.386365 | 0.0000 |
| $\ln DD$ | 0.317321 | 1.902371 | 0.0716 |
| ECM_{t-1} | -0.489734 | -3.277600 | 0.0038 |
| Adjusted <i>R</i> -squared | 0.997447 | | |
| Durbin Watson stat. | 2.300335 | | |
| <i>F</i> -statistics | 411.2422 | | |

population growth are also playing a significant role to increase energy consumption. The results are indicating that consumption of energy is increasing in both short run and long run under climatic changes. Like other developing countries, direct rebound effect prevails in Pakistan with high magnitude in the long run and short run as well. However, magnitude of rebound effect is higher in the long run as compared to short run. This may be because of unmet demand of electricity services in Pakistan wherein elasticity of demand due to effective price changes is high. The other reason can be the increasing wealth of households, which leads to greater demand of electricity due to increasing use of electric appliances in the long run.

The results also depict that with the increase in income level of households, demand of electricity rises. Population is also very important factor to consider in forecasting electricity demand, which do impact the policymaking as suppressed forecasting may lead to inappropriate or insufficient planning to ensure reliability of electricity supply. The evidence provided in the paper suggests that government of Pakistan should consider rebound effects along with climatic changes and population growth in formalizing its energy policies to achieve energy and environmental sustainability. Reliance on coal and other fossil fuels for electricity generation can be a point of concern to meet prevailing demand supply gap in the country but for the short run only. As a matter of long run policy, the government of Pakistan should also put emphasis on appropriate policy making and regulatory reforms to attract investment in the environmental friendly sources of electricity production, that is, renewables. This is how environmental and energy sustainability can be reasonably ensured.

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