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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.

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

$$P_s = \frac{P_E}{e} \tag{1}$$

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 Srepresents 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:

$$\eta_e = \frac{d\ln E}{d\ln e} \tag{2}$$

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

$$RE = 1 + \eta_e \tag{3}$$

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:

$$RE = -\eta_{Pe} \tag{4}$$

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:

$$P_{E_{it}} = P^{max}_{E_{it}} P^{cut}_{E_{it}} P^{rec}_{E_{it}} \tag{5}$$

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

$$\begin{aligned} P^{max}_{E_{it}} &= \max\left\{P_{E_{i1}}, P_{E_{i2}}, \ldots, P_{E_{it}}\right\} \\ P^{cut}_{E_{it}} &= \Pi^{t}_{m=0} \min\{1, ((P^{max}_{E_{im-1}}/P_{E_{im-1}})/(P^{max}_{E_{im}}/P_{E_{im}}))\} \\ P^{rec}_{E_{it}} &= \Pi^{t}_{m=0} \max\{1, ((P^{max}_{E_{im-1}}/P_{E_{im-1}})/(P^{max}_{E_{im}}/P_{E_{im}}))\} \end{aligned} \tag{6}$$

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:

$$\ln P_{E_{it}} = \ln P^{max}_{E_{it}} + \ln P^{cut}_{E_{it}} + \ln P^{rec}_{E_{it}} \tag{7}$$

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:

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

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.

$$DD = HDD + CDD \tag{9}$$

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