Applied Energy xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Exploring the direct rebound effect of residential electricity consumption: An empirical study in China ☆

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HIGHLIGHTS

- The direct rebound effect (RE) of China's residential electricity consumption is 72%
- The direct RE is about 68% (55%) in the low (high) income regime.
- The direct RE is about 75% (90%) in the low (high) cooling degree days regime.
- The direct RE is about 68% (86%) in the light (heavy) rainfall regime.
- The rise (fall) of GDP per capita (cooling degree days, rainfall) may reduce the RE.

ARTICLE INFO

Article history:
Received 12 September 2016
Received in revised form 22 November 2016
Accepted 16 December 2016
Available online xxxx

Keywords:
Residential electricity consumption
Direct rebound effect
Panel threshold model

ABSTRACT

Due to the energy rebound effect, the electricity conservation brought about by improving the electricity efficiency of China's households may be not as much as expected. Therefore, this paper employs the panel threshold model to investigate the direct rebound effect of China's residential electricity consumption under different kinds of regimes and its main influencing factors during 2000–2013. The results show that, first, the direct rebound effect (RE) of China's residential electricity consumption is about 72% on average. Second, the direct RE is about 68% (55%) in the low (high) income regime, and the increase in GDP per capita may help to reduce the direct RE. Third, the direct RE is around 75% (90%) in the low (high) cooling degree days regime, and the decrease in cooling degree days may reduce the direct RE. Fourth, the direct RE is around 68% (86%) in the light (heavy) rainfall regime, and the decrease of rainfall may help to reduce the direct RE. Finally, GDP per capita and population have significant positive impact on residential electricity consumption; while the impact of cooling degree days and rainfall appears relatively weaker.

1. Introduction

Nowadays, China has become the largest energy consumer and carbon emitter [1]. In 2015, China's primary energy consumption reached 3.01 billion tons of oil equivalent, accounting for 22.9% of the global total; meanwhile China contributed to 27.3% of the world's total carbon emissions [2]. As a responsible nation, China has paid more and more attention to global energy problems and climate change, and set a series of national targets for energy conservation and carbon emissions reduction [3,4]. For example, the Chinese Government targeted reduction of energy consumption per unit GDP to be 20%, 16%, and 15% through the 11th (2006–2010), 12th (2011–2015), and 13th (2016–2020) Five-Year Plan periods, respectively [5]. In reality, the energy intensity was reduced by 19% during the 11th (2006–2010) Five-Year Plan period, and the target of energy intensity reduction during the 12th (2011–2015) Five-Year Plan period was achieved. Additionally, China proposed that its carbon emissions would reach a peak in around 2030,[1] and targeted the reduction of carbon dioxide emissions per unit of GDP in 2030 to be 60–65% compared with that in 2005.[2] Over the past ten years, energy saving and consumption reduction is the main way to constrain energy consumption, and

☆ The short version of the paper was presented at CUE2016 on June 13–June 15, 2016, Jinan, China. This paper is a substantial extension of the short version of the conference paper.

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[1] http://politics.people.com.cn/n/2014/1113/c70731-26012421.html.
[2] http://news.xinhuanet.com/finance/2015-11/30/c_128481107.htm.

http://dx.doi.org/10.1016/j.apenergy.2016.12.087
0306-2619/

the most effective way to conserve energy is, as always, to improve energy efficiency [6].

The Chinese Government has taken a series of measures to conserve energy and reduce carbon emissions in dominant sectors, such as industry and transport [5], and the residential sector is also one worth targeting. According to the statistics, energy consumption in China's residential sector ranks behind only industrial energy consumption, accounting for 11% of the total energy consumed in China.[3] Fig. 1 shows China's residential energy consumption and its structure in 2002–2014. As seen, residential energy consumption almost increases annually. Besides, coal and electricity are the main energy sources supporting Chinese households, and the share of electricity use shows an increasing trend, ranging from 14.4% in 2002 to 18.68% in 2014. From this trend, we can conclude that residential electricity consumption plays a more important role in residential energy consumption. Meanwhile, electricity supply in China depends mainly on coal, whereas China is in the stage of optimising the structure of energy consumption in an effort to reduce the share of coal consumption. The residential sector is the key sector of electricity consumption, thus electricity efficiency improvements in households will contribute to optimising China's energy consumption structure and reaching the energy constraint targets to some degree. The Chinese Government has instigated electricity efficiency improvement plans. For example, the Energy Development Strategy Action Plan (2014–2020) mentions that the upgrade project of coal-fired units for energy conservation and carbon emission reduction should be performed, and coal consumption for generating electricity should be reduced to 300 grammes of equivalent coal per kilowatt hour within five years.[4] Additionally, during the 12th Five-Year Plan period (2011–2015), the demand side management has been strengthened, and price mechanisms have been commonly used to guide electricity efficiency improvements, for the sake of energy conservation and carbon emissions reduction.[5] Theoretically, improving electricity utilisation efficiency has important positive influence on reducing electricity consumption, the share of coal consumption, and greenhouse gas emissions, but why did the residential electricity consumption increase rather than decrease with the improvement of electricity utilisation efficiency in the past decade?

Except for the impact of economic growth, there are two aspects at play here. On the one hand, there may be an energy rebound effect. The effectiveness of improving electricity efficiency for energy conservation is not as great as expected, whereas there will be some rebound energy consumption [7]. Residential electricity consumption arises mainly from household appliances, such as air conditioners for controlling the temperature, refrigerators, rice cookers, washing machines, and home lighting for daily life, and computers and TVs for work or entertainment. When electricity utilisation efficiency improves, the power consumed doing the same work (lighting, heating, cooling, etc.) decreases. Therefore, the cost for equal energy services may decrease, which in turn leads to a change in behaviour, and residents increase the demand for buying or using the household appliances, thus electricity consumption increases. On the other hand, electricity utilisation improves with technologic progress, which promotes economic growth to some degree. This will raise the buying power of residents, and they may increase their demand for using or buying household appliances, which results in increased electricity consumption. Obviously, residential electricity consumption may vary in different external environments. For example, the electricity consumption in regions with lower buying power is often less than that in those with higher buying power. There are also differences in residential electricity consumption in cold north-eastern China, Yunnan with a permanent spring-like climate, and central China with four distinct seasons. Meanwhile, the rebound effect of residential electricity consumption may also be different in various external environments. Therefore, it is imperative to estimate the rebound effect of residential electricity consumption to avoid overestimating the effectiveness of energy efficiency policy. Also, it is of practical significance to estimate the heterogeneous rebound effect of residential electricity consumption for improving the effectiveness of energy efficiency policy in different external environments.

The contribution in this paper can be mainly summarised by three features: first, this paper investigates how the key factors (including residential electricity price, GDP per capita, population, cooling degree days and rainfall) have influenced China's residential electricity consumption, and the linear and non-linear relationships between the influencing factors and residential electricity consumption, and searches for the ways to restrain residential electricity consumption. Second, given the impact of the rebound effect on the effectiveness of residential electricity conservation and emissions reduction measures, this paper not only estimates the direct rebound effect of China's residential electricity consumption during 2000–2013 according to the price elasticity in linear relationship through the panel model, but also considers the direct rebound effect in non-linear relationship through the panel threshold model, and evaluates the energy conservation results of improving electricity utilisation efficiency in households. Finally, using GDP per capita, population, cooling degree days, and rainfall as threshold variables, this paper develops four panel threshold models and finds three kinds of regimes to estimate the different direct rebound effects of residential electricity consumption in different regimes, so as to find out the ways of reducing rebound effect and obtain targeted policy implications.

The remainder of this paper is organised as follows: Section 2 reviews related literature, Section 3 proposes models to investigate the main factors influencing residential electricity consumption and measure the direct rebound effect of residential electricity consumption as well as data definitions, Section 4 presents the results and detailed discussions, and Section 5 concludes the paper and proposes some policy implications.

2. Literature review

This paper reviews the literature mainly from the perspective of the factors influencing residential electricity consumption, the origin and mechanism of the energy rebound effect and the energy rebound effect of households as follows.

First of all, in terms of the factors influencing residential electricity consumption, existing research concentrates mainly on two aspects, i.e., economic factors and climatic factors [8]. There is a great amount of literature exploring electricity consumption characteristics in various countries. For example, Holtedahl and Joutz [9] use the level of urbanisation as a reasonable proxy for electricity-using equipment and examine the residential demand for electricity in Taiwan as a function of household disposable income, population growth, electricity price, cooling degree days, and urbanisation. The short- and long-term effects are separated through the use of an error correction model, and the empirical results indicate that the short-run income and price effects are small, and less than the long-run effects, besides, cooling degree day effects have a positive impact on short-run consumption. Craig and Feng [10] examine the relationship between residential electricity consumption, short-term climatic variability, long-term climatic trends, short-term reduction in electricity from energy efficiency programs, and long-term trends in energy efficiency programs in the United States. The results show that increasing cooling degree days significantly related to increased electricity use. Du

[3] http://data.stats.gov.cn/easyquery.htm?cn=C01.
[4] http://news.xinhuanet.com/energy/2014-11/20/c_127231835.htm.
[5] http://finance.sina.com.cn/g/20101118/11508972862.shtml.

Please cite this article in press as: Zhang Y-J, Peng H-R. Exploring the direct rebound effect of residential electricity consumption: An empirical study in China. Appl Energy (2016), http://dx.doi.org/10.1016/j.apenergy.2016.12.087