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Identifying electricity-saving potential in rural China: Empirical evidence from a household survey

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HIGHLIGHTS

- Electricity saving potential of rural households in China is examined.
- Unique survey data from the CRECS in collaboration with the CGSS are used.
- A stochastic frontier model is applied.
- Information feedback and social-demographic characteristics matter.
- Electricity price or energy efficiency tier rating does not matter.

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ABSTRACT

In recent years, there has been a fast-growing body of literature examining energy-saving potential in relation to electricity. However, empirical studies focusing on non-Western nations are limited. To fill this gap, this study intends to examine the electricity-saving potential of rural households in China using a unique data set from the China Residential Electricity Consumption Survey (CRECS) in collaboration with the China General Social Survey (CGSS), conducted nationwide at the household level in rural China. We use a stochastic frontier model, which allows us to decompose residential electricity consumption into the minimum necessary amount of consumption based on physical characteristics (e.g. house size, house age, number of televisions or refrigerators) and estimate the consumption slack (i.e. the amount of electricity consumption that could be saved), which depends on various factors. We find that rural households in China are generally efficient in electricity saving and the saving potential is affected by (fast) information feedback and social-demographic characteristics, instead of by the (averaged) electricity price, or energy efficiency labelling signals. In addition, we find no evidence of regional heterogeneity on electricity saving potential for rural households. Policy implications are derived.

1. Introduction

In 2014, China had more than 600 million people living in vast rural areas (World Bank, 2015). Due to rapid rural development, rural energy consumption has substantially increased in China, from 75.33 million tce (tons of coal equivalent) in 1992 to 158.65 million tce in 2012, with an annual growth of 7.7% (National Bureau of Statistics, 2014). Based on the population projection by the World Bank (2015), the total population of China will reach approximately 1.4 billion in 2030. Even if China can maintain stable urbanisation and reach an urbanisation rate of around 70% by that time, there will still be more than 400 million people living in rural areas. This means China faces a long-term challenge regarding energy consumption by the large population in rural areas. Combined continuing urbanisation, poverty reduction and energy structure transformation in wide rural China, the residential electricity demand would be expected to grow rapidly mainly resulted from more appliance ownerships (O'Neill et al., 2012; Auffhammer and Wolfram, 2014). For example, the ownership rate of colour television set in rural China increased from 4.7% in 1990 to 116.9% in 2012 dramatically. The ownership rates of washing machine and refrigerator also changed from 9.1% and 1.2% in 1990 to 67.2% and 67.3% in 2012, respectively (National Bureau of Statistics, 2015a). In an outlook of economic development and electricity demand in China, Hu et al. (2013) suggested that the residential electricity demand would reach 1332.2 TWh and

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2129.0 TWh in 2020 and 2030 according to a baseline scenario analysis. And it would grow to 3315.4 TWh and 4161.3 TWh in 2040 and 2050 by an input-output model.

In addition to the challenge of energy saving, residential electricity demand growth could make it difficult for China to meet its CO_2 emissions targets. China has made a commitment of achieving the peak of CO_2 emissions around 2030 or much earlier and increasing the share of non-fossil fuels in primary energy consumption to around 20% by 2030 (White House, 2014). Furthermore, China would also lower CO_2 emissions per unit of GDP by 60–65% from the 2005 level by 2030 (White House, 2015). Given that coal currently accounts for 78.2% of electricity generated (National Bureau of Statistics, 2015b), there would exist a conflict between electricity demand increase and emissions reduction strategies. Zhang et al. (2015) found that household energy consumption and its energy intensity are key driving factors to both indirect energy consumption and CO_2 emission. Thus, studies on rural household energy consumption, no matter whether they are aimed at improving the living conditions of rural people, reducing energy consumption, improving environmental quality, or promoting economic development, have practical implications. Although there are abundant studies on the above issues, special attention will be paid to households' energy-saving potential in rural China, particularly electricity-saving potential, which is as yet unknown.

Energy conservation and emission reduction are important issues in forming a long-term energy strategy. One strategy is to change households' energy consumption behaviour (Truelove and Parks, 2012; Yue et al., 2013). Energy-saving potential (for residential electricity consumption) has been found to be critical (Alfredsson, 2004; Carlsson-Kanyama et al., 2005; Benders et al., 2006; Vringer et al., 2007; Murata et al., 2008; Gardner and Stern, 2008; Dietz et al., 2009). For instance, using a questionnaire survey data from thirteen cities in China, Murata et al. (2008) estimated that a 28% reduction in electricity consumption by the year 2020 could be achieved through improving the efficiencies of end-use appliances. Gardner and Stern (2008) and Dietz et al. (2009) estimated that the energy consumption of U.S. households could be reduced by 20–30% by changing the selection and use of household and motor vehicle technologies.

Existing studies on residential electricity-saving behaviours are abundant,[1] and they provide vital information regarding the determinants of residential electricity-saving behaviour. However, there are few empirical studies addressing Chinese households' electricity-saving behaviour (Lu, 2006; Andrews-Speed, 2009; Ouyang and Hokao, 2009; Wang et al., 2011; Yue et al., 2013) and studies focusing on rural China are especially scant to the best of our knowledge.

To fill this gap, this study intends to examine the determinants of the electricity-saving potential of rural households in China using a unique data set from the China Residential Electricity Consumption Survey (CRECS) in collaboration with the China General Social Survey (CGSS) conducted nationwide at the household level in rural China. We use a stochastic frontier model, which allows us to decompose residential electricity consumption into the minimum necessary amount of consumption and estimate the amount of electricity consumption that could be saved.

This study differs from existing studies in two major respects. First, unlike the studies of Feng et al. (2010), Ouyang and Hokao (2009), Wang et al. (2011) and Yue et al. (2013), which targeted residents in a particular region in China (Hangzhou City, Liaoning Province, Beijing and Jiangsu Province respectively), this study focuses on rural households in China and uses the surveyed data covering 3404 rural households in 12 provinces.[2] Second, existing studies do not disentangle irreducible consumption (i.e. necessary consumption) and consumption slack (i.e. reducible consumption) from total residential electricity consumption; even though households may consume the same amount of electricity, the consumption slack or reducible consumption can vary depending on the household's electricity-using habits, social norms concerning energy saving, etc. Inspired by Yang et al. (2013) that energy saving potential of telecom operators in China is calculated by dividing total energy saving into technology part and management part, and by a recent study of Mizutani and Nakamura (2015), this study aims to identify the aforementioned two types of consumption and their driving forces using stochastic frontier methodology. The main result is that rural households in China are generally efficient in electricity saving with the average electricity efficiency score value of 93%. The electricity saving potential is affected by information feedback, instead of by the electricity price change, or energy efficiency labelling signals. Neither is there a regional heterogeneity effect. There are at least two important policy messages for policymakers. First, the transition of energy consumption structure is urgent since general electricity efficiency is high in rural China. Second, as a supplement of electricity tariff and China Energy Label System, the information feedback services need to be enhanced to discourage residential electricity use in rural China.

The rest of this paper is organised as follows. Section 2 presents a simple model of electricity demand. Section 3 discusses the stochastic frontier model, followed by the data sources introduced in Section 4. Section 5 presents the empirical results. The final section concludes with policy implications.

2. A simple model of the electricity demand frontier

Following Mizutani and Nakamura (2015), total electricity demand can be decomposed into two components, the irreducible amount regardless of price and the reducible amount due to a household's wasteful use of electricity. That is, the total amount of electricity demand q can be written as,

$$q = n(H|p_l < p < p_u) + s \tag{1}$$

where the total amount of electricity consumption (q) is the sum of the minimum necessary amount of electricity of a household n that is determined by the physical aspects of a household H (e.g. number of bedrooms, floor size, appliances, or family members) under the condition that price p is within the acceptable range for households ($p_l < p < p_u$), and the reducible amount s, the so-called "consumption slack". Assuming that the household maintains its current lifestyle, $n(H)$ can be interpreted as a fixed cost as the

[1] Existing studies on residential electricity-saving behaviours can generally be classified in relation to two aspects: internal incentives and external incentives. Internal incentives predominantly include demographic variables, such as the householder's age, gender, level of education and income (Becker et al., 1981; Al-Ghandoor, 2009; Zografakis et al., 2010; Gatersleben et al., 2002), attitude variables, such as the household's attitudes towards certain energy issues (i.e. energy scarcity) and pro-environmental awareness (Nord Lund and Garvill 2003; Abrahamse and Steg, 2009; Ek and Söderholm, 2010; Gadenne et al. 2011; Thøgersen and Grønhøj, 2010; Zografakis et al., 2010; Martinsson et al., 2011; Wang et al., 2011; Yue, et al., 2013), perceived behavioural control variables (Ajzen, 1991), such as the (in)convenience to households when engaging in particular electricity-saving behaviours (Linderderg and Steg, 2007; Banfi and Farsi, 2008; Feng et al., 2010; Scarpa and Willis, 2010; Wang et al., 2011; Yue et al., 2013), and past experience variables (Ajzen, 1991; Feng et al., 2010; Zografakis et al., 2010), such as an electricity crisis, or the Wenchuan Earthquake of 2008. External incentives include supportive government policies, such as taxes and subsidies, or media promotion for environmental protection (Ueno et al., 2006; Bartiaux, 2008; Ek and Söderholm, 2010), and demand response variables, such as daylight saving time and information feedback about electricity usage, such as enhanced billing, time-of-use pricing, "electronic in-house display" and "smart meters" (Faruqui and George, 2005; Herter et al., 2007; Fischer, 2008; Faruqui, 2010; Herter and Wayland, 2010; Faruqui and Sergici, 2011; Newsham and Bowker, 2010; Stevenson and Rijal, 2010).

[2] Note: provinces located in Southern China are Fujian, Guangdong, Hunan, Hubei, Jiangsu, Sichuan, Yunnan, and Zhejiang, whereas those located in Northern China are Gansu, Hebei, Heilongjiang and Shaanxi.

physical aspects are difficult (or not easy) to change and as the mid- or long-term aspect of electricity-saving behaviour. On the other hand, consumption slack (s) is a function of a household's level of effort to save electricity (e) and can be interpreted as a short-term aspect of electricity-saving behaviour, that is,

$$s = s(e) \tag{2}$$

where the level of effort to save electricity (e) is determined by maximising the following utility function of the household,

$$max\ U = B(e;\ Z) - C(e;\ Z) \tag{3}$$

where $B(\bullet)$ is the benefit from electricity saving and is an increasing function of e. In other words, more efforts to save electricity result in greater utility; for example, by saving electricity, a household can reduce its electricity expenses. $C(\bullet)$ is the cost of saving electricity and is a decreasing function of e. That is, more efforts to save electricity (e.g. by switching off lights or unplugging electronic appliances) engender discomfort for the household. Z is a vector of exogenous variables that are assumed to affect a household's utility function and hence the optimal level of saving effort (e^*). These variables are related to information feedback and the household's living habits, *inter alia*, and are denoted internal and external incentives by Mizutani and Nakamura (2015). Thus,

$$e^* = e^*(Z) \tag{4}$$

Through substitution, Eq. (1) can be re-written as,

$$q = n(H|p_l < p < p_u) + s(Z) \tag{5}$$

which forms the basis for the empirical implementation in this study.

3. Empirical model and methodology

The method adopted is that of Aigner et al. (1977), which estimates the stochastic cost function as:

$$Y_i = f(X_i;\ \beta)exp(\varepsilon_i) = f(X_i;\ \beta)exp(V_i - U_i),\ i = 1,\ 2,\ \ldots,\ N \tag{6}$$

where Y_i is the electricity consumption for resident i, X_i is a vector of explanatory variables, β is a vector of unknown parameters to be estimated and ε_i is the error term, which consists of two statistically independent components, V and U, both of which are independent of X. V are further assumed to be independently and identically distributed (*i.i.d*) random variables with $V \sim N(0,\ \sigma_v{}^2)$, while U_i are nonnegative random variables that account for technical inefficiencies in electricity consumption. Specifically, U_i are assumed to be independently normally distributed with $U_i \sim N^+(z_i\delta,\ \sigma_u{}^2)$ truncated at zero. The parameters of the model are estimated using the maximum likelihood estimation (MLE) method via maximising the log-likelihood function given by $\ln L = n\ln(2/\pi)^{1/2} + n\ln(1/\sigma) + \Sigma\ln[1 - \Phi(-\varepsilon\lambda/\sigma)] - \Sigma(\varepsilon^2)/2\sigma^2$, where $\sigma^2 = \sigma_u{}^2 + \sigma_v{}^2$, $\lambda = \sigma_u/\sigma_v$ and $\Phi(\bullet)$ is the standard normal distribution function.

The technical inefficiencies (U_{it}) in Eq. (6) can be specified as:

$$U_i = z_i\delta + W_i \tag{7}$$

where z_i are explanatory variables that explain the level of technical inefficiency of electricity consumption, δ is the vector of parameters to be estimated, W_i is defined by the truncation of the normal distribution with zero mean and variance $\sigma_u{}^2$, such that the point of truncation is z_i. The technical inefficiency for resident i is then calculated as $TE_i = Y_i/Y_i^* = F(X_i;\ \beta)\exp(V_i - U_i)/[F(X_i;\ \beta)\exp(V_i)] = \exp(-U_i) = \exp(-z_i\delta - W_i)$, where Y_i is the observed electricity consumption and Y_i^* is the "frontier consumption". The prediction of technical inefficiency is based upon the conditional expectation: $E(TE_{it}) = E(\exp(-U_i)|\varepsilon_i)$ (Battese and Coelli, 1988). The econometric computation was performed using the software package Frontier 4.1 (Coelli, 1996).

4. Data description

The data in this study were drawn from the CGSS of rural residents, carried out in 12 provincial units of China in 2014. The CGSS, which was jointly promoted by National Survey Research Center at Renmin University of China and the Survey Research Center at the Hong Kong University of Science and Technology, is a comprehensive general social survey which has been conducted periodically since 2003 and resembles the General Social Survey in the U.S.

The samples were selected using a combination of probability proportional to size (PPS) and multi-level random sampling techniques. In the first stage, the districts (i.e. prefecture-level cities, provincial capitals and centrally administrated municipalities and their suburban districts) and counties were the primary sampling units. In the second stage, the residential districts, villages and towns were the secondary sampling units. In the third stage, the neighbourhood and village committees were the tertiary sampling units. In the fourth stage, one person from each household was the final sampling unit. To be more specific, four residential districts/villages/towns (secondary sampling units) were chosen from one selected district/county within each of twelve provincial units surveyed (primary sampling unit); next, two neighbourhood committees/village committees (tertiary sampling units) were randomly selected from every selected secondary sampling unit; finally, approximately 10–15 rural residents were chosen from every selected tertiary sampling unit (for more details, please refer to the CGSS Project Group (2009)). As a result, a total of 3404 household-level questionnaires were completed in 2014. Fig. 1 shows the regional distribution of the surveyed households.

In relation to this study, the "energy module" of the questionnaire, among several other modules in the 2014 CGSS, was designed by the China Residential Energy Consumption Survey (CRECS) Center of the Renmin University of China. The energy module is based strongly on the US Department of Energy and Energy Information Administration Residential Energy Consumption Survey. The questionnaire covered six areas: household characteristics, dwelling characteristics, household appliances, space heating and cooling, patterns of private transportation and electricity billing, metering and pricing options. According to the surveyed data, we find that the annual average energy consumption of a rural household is 1289 kgce. Energy types include coal, diesel, liquefied petroleum gas (LPG), natural gas, electricity, heating power, solar and other biomass energy, such as firewood, which supplies 58% of the total energy demand. All of firewood is used for cooking and distributed heating, which accounts for 56% and 44% respectively. Coal makes up 13% of the total energy consumption, 94% of which is used for distributed heating. Electricity accounts for 11% of the total energy consumption, mostly used for powering household appliances (55% of the total electricity demand) and cooking (25% of the total electricity demand). In accordance with common views, LPG is very popular in the countryside, while district heating system is not established widely. The calculation methods and surveyed descriptive results are similar to Zheng et al. (2014).

In the model of residential electricity consumption, the dependent variable is the resident's reported electricity consumption (*Y_rec*). To deal with potential data error and outliers, following common practice in the literature, electricity consumption measure is winsorized at the 0.5% level to reduce the weight of extreme values using the Stata module *winsor2*. Fig. 2 shows the kernel densities of the household's electricity consumption. The mean value is 1224 kWh/household, with the median value of 1000 kWh/household. In addition, it can be observed that the electricity consumption is highly concentrated at 1000 kWh/household, and widely dispersed to 7200 kWh/household.

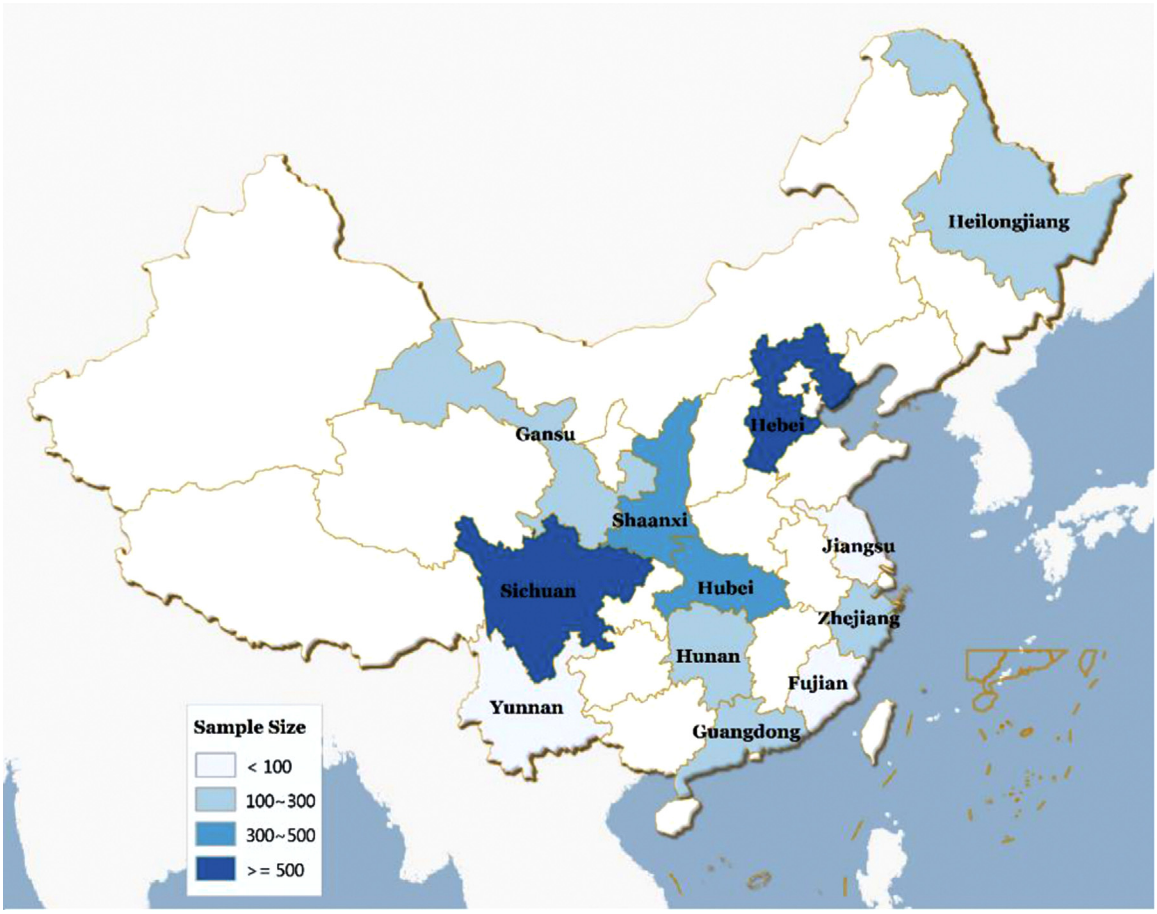

Fig. 1. Regional distribution of surveyed households.

The following variables are identified to possibly affect the household's minimum necessary amount of electricity.

4.1. Dwelling characteristics

This includes house area (*X_hsize*) and house age (*X_hage*). In the sample surveyed, 65% of respondents had a house with an area greater than 100 m^2 with mean and median values of 123 m^2 and 105 m^2 respectively. As the housing size increases, residential electricity consumption is also expected to increase. Buildings of less or equal to 30 years old accounted for 90% of all houses surveyed and most buildings (2509) were built approximately 10–30 years ago. In contrast, the newest buildings, which are built after 2010, accounted for 10% of total surveyed households. Dwelling age influences residential electricity consumption in two respects. On the one hand, relatively new houses are more likely to be equipped with more electronic appliances, which push up electricity demand. On the other hand, relatively new houses may imply more advanced construction materials and the use of more energy-efficient electronic heating and cooling systems, which makes the house more energy efficient (e.g. keeping the house warmer in winter).

4.2. Family size

This is measured by the number of family members (*X_person*). Those surveyed on average had three members (676, 21% of surveyed households) in the family. Other things being equal, a larger family size tends to use more electricity.

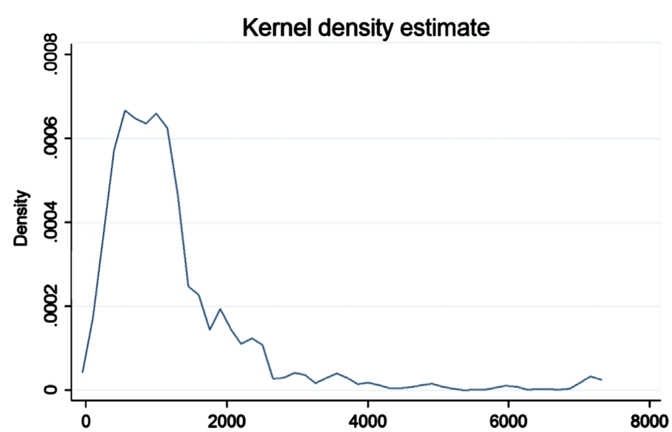

Fig. 2. Kernel densities of electricity consumption (kWh/household).

4.3. Housing appliances

This variable primarily relates to the number of durable electronic appliances, such as refrigerators (including freezer) (*X_refrig*) and televisions (*X_tv*), in the home. The ownership of refrigerators and televisions per 100 household are 75.35 sets and 98.59 sets respectively. Most families surveyed had only one refrigerator (2413) and one television (3112). When more electric appliances are used, residential electricity consumption is expected to rise generally.

Turning to the technique for the inefficiency function, the following variables are taken into account as affecting the residents' electricity-saving behaviour:

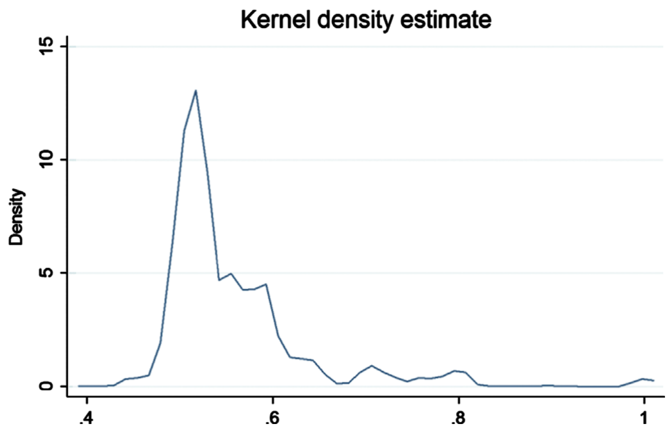

Fig. 3. Kernel densities of average electricity price (Yuan/kWh).

4.4. Electricity price

The price of electricity is a key component of electricity consumption behaviour (*Z_price*). The theory tends to assume that people will respond to the marginal price. However, the households surveyed actually faced a constant price. People tend to respond to average price because of incomprehensible price-setting and information barriers (Ito, 2012). To capture the price effect in residential electricity consumption behaviour, we used the average price, which is defined as the household's total electricity expenditure divided by the total amount of electricity the household used (Filippini and Pachauri, 2004). The residential electricity price (averaged) is calculated to be approximately 0.56 Yuan/kWh, with median value of 0.52 Yuan/kWh, and 1.00 Yuan/kWh and 0.40 Yuan/kWh being on the top and bottom 10 percentiles respectively. Households are likely to be more efficient in terms of electricity consumption if they face a higher electricity price. Fig. 3 plots the kernel densities of average electricity price, which is concentrated at 0.52 Yuan/kWh and mainly dispersed from 0.40 Yuan/kWh to 1.00 Yuan/kWh, which is much higher than the electricity price administrated by Chinese governments. This phenomenon implies that if residential electricity demand is price elastic, households are likely to be more efficient in terms of electricity consumption when they face a higher electricity price.

4.5. Information feedback

Information feedback (including detailed electricity bills, self-reading metres, or in-home display) is considered to be an important tool for future utility demand-side management. Feedback can be instrumental in reducing a household's electricity consumption through several channels, potentially affecting the resident's habitual behaviour, such as turning off lights or unplugging appliances (Jacucci et al., 2009; Bekker et al., 2010), or affecting the resident's appliance purchasing choices in terms of replacing energy-consuming appliances with more efficient ones (Fischer, 2008). Feedback has been found not to be trivial. In general, based on a review of the literature on metering, billing and direct displays, the feedback mechanism is found to be able to reduce residential electricity consumption from 5% to 20% in different regions (Darby, 2006). Gleerup et al. (2010) found that timely information concerning a Danish household's exceptional consumption communicated via email and text message resulted in average reductions in total annual electricity use of about 3%.

In this study, information feedback is characterized by the frequency of paying electricity bills (*Z_freq*), which is a dummy variable taking the value 1 if the electricity bill was paid on a monthly basis and a value of zero otherwise. In the surveyed sample, monthly payment is observed to be the most common payment method, which accounted for 61% of all payment mode, whereas 30% of households paid the electricity bill quarterly, 5% made the payment semi-annually. We hypothesise that more frequent feedback leads to less electricity demand. A number of studies conclude that feedback frequency is a key factor in energy savings (Fischer, 2008; Wood and Newborough, 2003). As Fischer (2008) suggested, quick feedback improves the link between consumers' actions and effects; consequently, it increases consciousness about the action's outcome.

4.6. Social-economic characteristics

These include the years of education of the head of the household (*Z_edu*) and the household's income (*Z_income*). The resident's level of education is represented by the years of schooling. In all, 60% of the respondents only had a level of education equal or less than 6 years. 9% of the respondents had a level of education of more than 12 years and the greatest length of education was 19 years. The average schooling years was 6.09 years, with the median value of 6 years. Existing studies, from a much earlier study by Reizenstein and Barnaby (1976) to recent studies by Martinsson et al. (2011) and Wang et al. (2011), found mixed results on the association between education and energy conservation, an earlier survey on the link with those two can be found at Semenik et al. (1982). Regarding electricity usage, education has two distinct effects on electricity demand. On the one hand, households with highly-educated members tend to consume less electricity because they have a greater awareness of energy conservation and environmental concerns. On the other hand, more highly educated households are normally associated with higher income groups, which could result in an increase in electricity use. Therefore, the efficiency effect of education is ambiguous. The household's income (*Z_income*) is reported by the surveyed resident, which ranges from 1000 Yuan/year to 1 80,000 Yuan/year with a mean value of 35,920 Yuan/year and a median value of 29,600 Yuan/year. Income, as one factor that is most studied for its relationship to energy conservation, is not highly predictive of electricity usage or saving potential, some studies reported positive associations between energy conservation and income (Talarzyk and Omura, 1974; Grier, 1976; Sardianou, 2007; Hori et al., 2013), other studies found negative associations (Al-Ghandoor et al., 2009; Thøgersen and Grønhøj, 2010; Martinsson et al., 2011; Sahin and Koksal, 2014), and still other studies found no significant relationship between those two (Wang et al., 2011, Mizobuchi and Takeuchi, 2016). Furthermore, the inconsistent pattern of findings are found for conservation of specific type of energy that is examined separately. In terms of electricity, on the one hand, households with higher incomes, a factor frequently related to social consciousness in attitudes and behaviour, are not likely to be found among the lowest energy consumers as they are more likely to purchase large electrical appliances and use them more frequently (or longer) than before; on the other hand, the higher income households can be more willing to perform conservation activities which often require monetary outlays, like installing fluorescent lights, or purchasing high-efficiency refrigerators or air conditioners.

4.7. Energy-saving consciousness

This indicator variable reflects the standard a household adopted in buying appliances such as televisions and refrigerators (*Z_tv, Z_refrig*). Currently, the label classifies appliances into five tiers with tier one being the most efficient and tier five being the least efficient. In this study, we define the aforementioned two indicator variables, which take a value of 1 if the electronic appliance is in the tier one category and a value of zero otherwise. In the surveyed households, 1189 refrigerators and 50 freezers are in standard of tier one, and 70% of total refrigerators (including freezers) are marked as high efficiency, i.e., belong to the tier 1–3 category. For television,

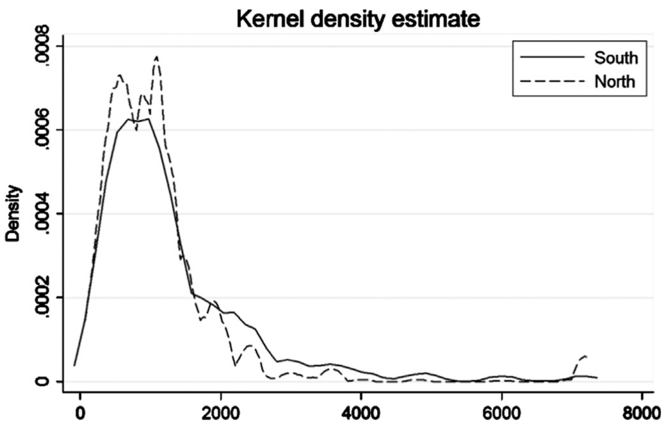

Fig. 4. Kernel densities of electricity consumption by regions (kWh/household).

only 298 televisions are in standard of tier one, and only 18% of total televisions belong to the tier 1–3 category. Intuitively, a household's use of energy-efficient appliances provides some evidence of electricity saving; however, the rebound effect of electricity appliances could lead to more electricity consumption.

4.8. Regional heterogeneity

The explanatory variables as proposed in the inefficiency equation may be limited, as region-specific characteristics not captured by the aforementioned explanatory variables may affect the efficiency of a household categorized in that region. Thus, to control for unobserved regional heterogeneity, a dummy variable (*Z_region*) is added in the econometric model, which takes a value of one if the households are located in South China (Fujian, Guangdong, Hunan, Hubei, Jiangsu, Sichuan, Yunnan, and Zhejiang in our surveyed sample) and a value of zero if the households are located in North China (Gansu, Hebei, Heilongjiang and Shaanxi). Fig. 4 shows the kernel density of electricity consumption by regions. It can be seen that the distributions of electricity consumption are different in the two regions. Comparing with households in North China, households in South China had slightly concentrated electricity consumption, with longer right tail and also larger mean value. Moreover, based on the surveyed data, South China residents depended on more heavily on electricity than that of North China household, 14% of their energy demand is due to electricity, while the number is only 8% in North China. So far, we have no expectation regarding whether one region operates more efficiently than the other, *ceteris paribus*.

Table 1 presents the descriptive statistics for the variables used in the stochastic cost function and the inefficiency function.

5. Empirical results

The estimation results are shown in Table 2. After removing missing data from the surveyed sample, we eventually obtained a total of 1586 observations used in this study. The upper part shows the result of Eq. (6), which has *Y_rec* as the dependent variable. The lower part shows the result of Eq. (7), which has electricity consumption slack (the inefficiency term) as the dependent variable. These two equations are simultaneously estimated by MLE and empirically implemented in Frontier 4.1 (Coelli, 1996).

These estimation results seem to be reasonable. The Wald chi-square statistic (338.13, $p=0.000$) indicates that the explanatory variables chosen have significant importance in explaining electricity consumption. Second, most variables show the expected signs. The fact that the coefficients of *X_hsize*, *X_person*, *X_refrig* and X*_tv* are positive indicates that as the house becomes larger or has more refrigerators or TV sets, more electricity is required to maintain the household's lifestyle. These results are consistent with those of Thøgersen and Grønhøj (2010), showing that larger households consume more electricity, as well as those of Faruqui and George (2005), suggesting that those characteristics are important for electricity consumption. In contrast, the coefficient of *X_hage* is negative, but statistically insignificant at the conventional 5% level, implying that building age has neither an electricity-conserving nor an electricity-wasting effect, *ceteris paribus*. This result may seem to be surprising at first sight, but recognising that we are modelling rural households' electricity use rather than energy use *per se*. About 80% of total electricity consumption is used for cooking and appliances in rural China, which is reasonable as the amount of electricity used by one household will not change no matter how old the house is.

Turning to the lower part (i.e. consumption slack), showing the results of Eq. (7), several important results can be identified. First, the statistically insignificant electricity price variable implies that rural households' saving potential is not affected by the price of electricity. In other words, rural households would not become more efficient in terms of electricity consumption were a higher electricity price to be imposed. A possible explanation is that some households use the electricity to meet their basic demand or even less than the basic demand. Compared with electricity, biomass energy plays a dominate role in rural energy consumption because it is easily accessible. For electricity consumption, there is an obvious gap in households located in urban and rural China. In 2012, the electricity consumption are 1893 kWh per household annually in urban and 1389 kWh per household annually in rural area, respectively (Zheng et al., 2014). From the point of appliance ownership, the ownership rate of household appliances per 100 households is much lower in rural regions except that the ownership rate of televisions has a relatively high number of being 118.3 sets. While the ownership rates of refrigerators, washing machines, air conditioners, and personal computers are 67.3, 67.2, 25.4 and 21.4 sets, respectively (National Bureau of Statistics, 2015b). Therefore, the response of rural residential electricity demand to price change is weakened by easily accessible substitute energy (biomass energy) and lower dependence on electricity.

Second, information feedback is important in terms of affecting the residents' electricity-saving behaviour, evidenced by the negative coefficients of *Z_freq* with statistical significance. These results indicate that paying the electricity bill more frequently (on a monthly instead of a quarterly or semi-annual basis) increases the efficiency of electricity use, suggestive of the important role of (fast) information feedback on affecting a resident's electricity-saving behaviour.

Third, as mentioned earlier, empirical studies on the relationship between education and energy conservation or between income and energy conservation are mixed. In this study, there appears a positive relationship between a householder's education or income and electricity saving, which is in line with Sardianou (2007) and Hori et al. (2013), and arguably with the general expectation that conservation and education or income would be positively associated.

Fourth, the coefficients for *Z_tv* and *Z_refrig* are both negative but statistically insignificant at the conventional 5% level of significance, which is surprising as the general expectation is that promoting high-efficiency appliance is effective in electricity saving as found in some studies like Liu et al. (2014). A tentative explanation to this result is that there could be rebound effect (which occurs when energy efficiency of products improves, people just use more of these products) that cancels out the household's electricity savings, resulting an overall insignificant effect on electricity usage.

Last, we find no evidence of regional heterogeneity ($p=0.948$) on electricity saving potential for rural households in China. This result appears surprising as well at a first glance. However, the indifference of electricity saving potential across regions shall be

Table 1
Descriptive statistics of variables.

Variable	Definition	Obs.	Mean	Std. Dev.	Min	Max
Electricity consumption function						
Dependent variable						
Y_rec	Reported residential electricity consumption (kWh)	3198	1224.02	1078.43	60.00	7200.00
Independent variable						
X_hsize	Floor area (m^2)	3215	122.69	61.23	7.50	250.00
X_hage	Dwelling age (year)	3203	19.89	13.29	5.00	66.00
X_person	Family member	3244	3.05	1.48	1.00	16.00
X_refrig	No. of refrigerators	2489	1.03	0.17	1.00	2.00
X_tv	No. of televisions	3234	1.04	0.19	1.00	2.00
Inefficiency function						
Z_price	Calculated electricity price	2695	0.56	0.08	0.40	1.00
Z_freq	Paid electricity bill monthly	3274	0.63	0.48	0.00	1.00
Z_edu	Household head's education (year)	3265	6.09	3.73	0.00	19.00
Z_income	Household yearly income	3147	35920.16	32446.81	1000.00	180000.00
Z_tv	TV labelling tier one	3095	0.19	0.39	0.00	1.00
Z_refrig	Refrigerator labelling tier one	2441	0.72	0.45	0.00	1.00
Z_region	South=1	3404	0.55	0.50	0.00	1.00

Table 2
MLE estimates of the electricity consumption function and inefficiency function (Dependent variable: ln(*Y_rec*)).

	Coefficient	*P*-value
Frontier function		
X_hsize	7.979[c]	0.000
X_hage	−6.012[a]	0.061
X_person	12.498[b]	0.038
X_refrig	31.729[b]	0.025
X_tv	116.234[a]	0.084
Constant	96.283	0.400
Efficiency function		
Z_price	−309.206	0.132
Z_freq	−26.633[c]	0.008
Z_edu	−10.580[a]	0.070
Z_income	−0.018[b]	0.023
Z_tv	−101.789[a]	0.076
Z_refrig	−45.712[a]	0.084
Z_region	15.269	0.948
Constant	44.419[c]	0.000
Wald test	338.13[c]	0.000
Obs.	1586	
Log-likelihood	−13,520.00	

Notes: Absolute *t* values are reported in parentheses. The coefficients in the inefficiency function are inefficiency effects and therefore a positive coefficient implies a negative effect on performance, or a reduction of efficiency.

[a] $p < 0.10$.
[b] $p < 0.05$.
[c] $p < 0.01$.

expected when the following three factors are taken into account: (i) we are targeting at the saving behaviour of a particular energy type (electricity) from a relatively small group of people (rural households) in China; (2) several major determinants of saving potential such as rural household's income, level of education, information feedback, and appliance labelling information are controlled for; (3) Chinese people, especially rural residents in China, have been maintaining the virtue of thrift in their daily life. All these factors considered together shall mitigate, to a large extent, the regional difference (if there is any) of energy saving potential of rural households in China. Hence, the result of regional homogeneity found in this study will not be surprising anymore.

It is worth mentioning also that the energy efficiency score can be obtained for each household via $E[\exp(-u|\varepsilon)]$, the Battese and Coelli (1988) estimator. The estimated average efficiency score is 93%, implying that during the time analysed, the rural households on average were highly efficient.

6. Conclusion and policy implications

Using a unique data set from the China Residential Electricity Consumption Survey (CRECS) in collaboration with the China General Social Survey (CGSS) conducted nationwide at the household level in rural China, this study intended to examine households' electricity-saving potential in rural China. By applying the stochastic frontier model, we were able to decompose residential electricity consumption into the minimum necessary amount of consumption (irreducible part) and the amount of electricity consumption that could be saved (reducible part). We find primarily that rural households in China are generally efficient in electricity saving and the saving potential is affected by (fast) information feedback and social-demographic characteristics, instead of by the (averaged) electricity price, or energy efficiency labelling signals. It is an opportunity for promoting structure transformation in energy consumption because of high electricity efficiency in rural China. To help the government design and implement appropriate policy options, several policy implications can be drawn from different perspectives, each of which is delineated in turn below.

6.1. Price policy

The rural household's saving behaviour shows no response to rural electricity prices, reflecting the fact that electricity is commonly used for cooking and household appliances to meet the basic needs of living in rural areas. This may imply that a price policy will not be effective as it cannot encourage rural households to buy more energy-efficient appliances or replace existing appliances with more energy-efficient models. Recently, China's State Council has issued several documents concerning power sector reforms in relation to electricity generation, retail, use and many other sectors. One of these documents, known as Policy No. 9 (*Several Opinions of the CPC Central Committee and the State Council on Further Deepening the Reform of the Electric Power System*), suggested that urban–rural electricity cross-subsidies should gradually be phased out, which engendered hot debates on its policy consequences; one widespread argument is that removing urban–rural electricity cross-subsidies might push up the residential electricity price. While the possible effects on rural households due to these reforms remain unclear, we find in this study that a potential increase in price would have no effect on the rural households' electricity use behaviour.

6.2. Efficiency labelling

Most appliances today include a label stating the average efficiency rate. The energy efficiency labelling is, however, found to have no effect for electricity conservation in rural households (at the conventional 5% level of significance), which is perhaps attributed to the rebound effect which cancels out the household's potential electricity savings. Given their low income level, rural households have less incentive to invest in advanced energy-efficient products or replace existing household appliances. In this regard, it is suggested that Chinese government's rural appliance subsidy programme, launched in 2009, and the one-year subsidy programme for energy-efficient home appliances, launched in 2012, both of which expired in 2013, should continue for the sake of rural energy conservation.[3] But this subsidy programme as mentioned above alone does not help to conserve electricity, policy mixes for energy efficiency and conservation is deserved.

6.3. Information feedback

Information feedback variables (frequency of paying electricity bills, metre reading, etc.) play critical roles in the electricity-saving potential of rural residents. This result suggests that except for the improvement in the electrification process on the supply side, the improvement in electricity service on the demand side is equally important in rural China. Consistent with earlier research (Henryson et al., 2000; Murata et al., 2008; Gleerup, 2010; Gans et al., 2013; Gilbert and Graff Zivin, 2014), more feedback – particularly that which is expedient and frequent – tends to conserve energy, implying that providing better feedback services to rural households is necessary and meaningful for energy conservation.

6.4. Electricity saving

One caveat should be mentioned in this study regarding the stochastic frontier modelling. According to our survey, solar and other biomass energy play a dominant role in rural China, while electricity only accounts for 11% of total energy usage and is mainly used to meet the basic needs of living such as lighting, cooking and household appliances. This phenomenon is related to costs and tradition of energy uses. It is likely that some households over save the use of electricity and their electricity consumption are less than basic demand. The reducible amount should be zero, or the estimated reducible part may be higher than the actual electricity usage, yet, the frontier model used in this study may not capture this situation. Though perhaps problematic, the estimated high level of electricity efficiency score (93% on average) suggests that the adjustment of energy structure in rural China is more urgent than electricity saving,[4] continued research is needed towards this direction.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2016.03.031.

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[3] The programme was launched on 1 June 2012 to offer subsidies ranging from 100 to 400 yuan ($16.18 to $64.72) for every energy-efficient home appliance sold (China Daily, 2013).

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