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Abstract

With rapid economic growth, total energy demand in rural China has increased dramatically and its structure is in the transition from non-commercial to commercial energy. At the same time, it is also expected that households in rural areas will face energy shortage and causes more environmental problems without having more access to renewable energy technologies. However, little is still known about (i) the transition of the energy use and (ii) whether the technologies introduced have been effective or not. To analyze these issues, we have estimated energy demands of rural households by utilizing a survey data taken from Beijing's ten suburban districts. The data contains the information of both non-commercial and commercial energy use, key characteristics of the households and several renewable energy technologies. Our empirical analysis reveals three main results. First, the per capita income is a key factor to per capita energy consumption. More specifically, a rise in per capita coal consumption strongly diminishes as per capita income increases. Second, coal and LPG prices do not exhibit any substitution effect, but an increase in these prices has strong negative effects on their own energy use. Third, the renewable energy technologies are identified to reduce the coal consumption and induce more energy efficiency. Overall, these findings suggest a positive perspective: if the Chinese government could appropriately design policies associated with renewable energy technologies and with the related energy price controls, then coal consumption will be induced to decline in the near future and the substitution effects to cleaner energy use will speed up. This implies that the smooth energy transition in rural China can be made in more environmentally sustainable manners.

Key Words: energy demand, rural households, renewable energy technologies, energy price
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1 Introduction

With the rapid economic development since 1978, China's total energy demand has been increasing dramatically. Accordingly, an energy consumption pattern in Chinese rural households has also experienced great structural changes. During the period of 1979-2005, the proportion of commercial energy consumption in rural areas has increased from 17% to 44%, while that of traditional biomass resource has decreased from 70.79% to 34%; however, in the mix of commercial energy, coal has been the dominant source of primary energy (Zhang et al. (2009)).

The coal consumption is considered as a main cause for accelerating the adverse effect on the environment. In particular, coal combustion is the main contributor to China's CO_2, SO_2, NOx and TSP emission, which directly threatens public health and generates acid rain in some regions of China. Meanwhile, fuelwood and crop residues still remain to be important energy resources for most of the Chinese rural households. The direct burning of straw and firewood can result in incomplete combustion, which leads to large emission of CO_2 and other toxic gases (Zhou et al. (2008)).

For the past sixty years from 1949 to 2008, the Chinese government had been promoting renewable energy use to mitigate environmental problems. Before 1978, the government advocated and promoted the use of methane in rural areas. With the rapid economic development since 1978, he has further diversified the range of renewable energy use; research and application on solar, wind power, biomass and geothermal energy have been highly encouraged. Since the enactment of Renewable Energy Law of China in 2006, the development of renewable energy has been further promoted. Compared to 2005, the proportion of renewable energy use to total primary energy consumption has increased from 7% to 9% in 2008 (Junfeng (2009)).

Promotion of diversified renewable energy technologies in rural China is expected to play a more important role in optimizing energy consumption structure, and reduce the environmental problems. This expectation reflects the fact that 55.06% of Chinese people live in rural areas at the year of 2007 and it is reported that renewable energy consumption is important to have a better environment in China (National Bureau of Statistics of China (2008) and Gehua (2008)). Therefore, understanding the determinants of rural household energy choices is extremely salient to take future countermeasures against unreasonable energy use that currently prevails in many parts of rural China. Furthermore, it is also argued that evaluation of the effectiveness on different types of renewable energy technologies is a necessary step toward designing future policies on their implementation (Chen et al. (2006)).

Recent years, several studies on China's rural energy consumption have been conducted. Many of these studies focus on macro-level analysis to derive policy implications (See, e.g., Jiang and O'Neill. (2004), Zhou et al. (2008) and Zhang et al. (2009)). Unfortunately, however, it is pointed out that China has significant heterogeneity among different regions and locations. Thus, some authors argue that such macro-level analysis may be too general to give some implication for a feasible nationwide policy (See, e.g., Chen et al. (2006)).

There exist some studies focusing on micro-level rural energy consumption by utilizing household survey data (Heltberg et al. (2000), Chen et al. (2006) and Demurger and Fournier (2006)). In Chinese cases, Chen et al. (2006) find that possession of improved stove does not affect fuelwood consumption in the remote villages, but increases it in villages with good market access. Similar to Chen et al. (2006), Demurger and Fournier (2006) focus on the analysis of fuelwood and coal consumption in rural China. Their result shows that household economic wealth is a significant and negative determinant of fuelwood consumption. They further find that fuelwood consumption changes with income in a U-shaped manner.

Although these studies give some important insights into traditional energy consumption of fuelwood and coal, none of previous studies analyze the pattern of energy use transition from non-commercial to commercial energy at micro-economic levels. Such an investigation on the transition of energy consumption in rural areas is particularly important when Chinese economy drastically grows and has experienced a drastic structural change. Furthermore, few studies systematically evaluate and quantify the effectiveness of different renewable energy technologies in the energy consumption of rural households, which has been promoted by Chinese governments. Given this of affairs, this paper seeks to tackle these important issues by empirically examining energy demands in rural China.

To develop a research in this crucial subject, we have implemented a random household survey involving Beijing's ten suburban districts in July 2009. The collected data contains overall types of energy resource consumption: commercial energy (coal, electricity and LPG (Liquefied petroleum gas)), non-commercial energy (fuelwood and crop residues), potential determinants such as household characteristics, and renewable energy technologies installed in households such as solar or biomass related technologies. The renewable energy technologies examined in this research are categorized into seven types that have been widely promoted by the government in Beijing's rural areas: solar street lights (S1), solar heating system (S2), energy-efficient new house (S3), building energy efficient retrofits (W1), biomass gasification and gas-supply system (B1), household anaerobia digesters (B2) and biomass stove (B3).[1]

The unique attribute of this data is that we surveyed the households who utilize a wide range of energy resources: not only low-efficiency energy such as coal and fuelwood, but also high-quality commercial energy such as clean energy from various Beijing's rural areas. On the one hand, the data in the other previous studies is only obtained from households who exclusively utilize traditional and non-commercial energy such as coal and fuelwood. This novelty in our data enables us to make a unique contribution to the existing literature.

Here note that there are two main reasons to explore the survey in Beijing's rural areas. One reason is high heterogeneity among the households of rural Beijing with respect to the characteristics, various socio-economic levels, geographical locations, and available energy resources. Therefore, we can easily obtain a huge variation of the data by conducting a survey in a relatively small area. For instance, almost all households in the survey areas still highly rely on coal as energy sources, however many of them consume traditional biomass

[1]The detailed definitions of seven renewable energy technologies are given in the appendix.

resources or renewable energy such as solar at the same time. Therefore, research in Beijing's rural areas is one of the most convenient choices to reflect overall features for both poor and rich regions and for both commercial and non-commercial energy consumption.

The second reason is associated with the government policies conducted in rural Beijing areas. That is, considerable energy policies have been implemented and renewable energy technologies have been installed in Beijing's rural regions under government administrations. For example, in 2006, three energy strategies were vigorously implemented in Beijing: "Lighting the village," "Warming peasants' house," and "Recycling the agricultural wasted resources," all of which are promoted through further utilization of renewable energy technologies.

More specifically, solar street lights (S1) have been widely promoted to achieve the target of "Lighting the villages." "Warming peasants' house" refers to improving building energy efficiency and indoor living comfort. To achieve this target, solar heating system (S2), energy-efficient new house (S3), building energy efficient retrofits (W1) have been popularized. "Recycling the agricultural wasted resources" indicates fully making use of the wasted biomass resources. This paper covers three "Recycling" technologies: biomass gasification and gas-supply system (B1), household anaerobia digesters (B2) and biomass stove (B3). Therefore, analysis on the data taken from the areas can reveal which type of renewable energy technologies works better than the others.

With this unique household survey data, we estimate a system of energy demands spanning three commercial energy consumptions (coal, electricity and LPG), and two non-commercial energy consumptions (fuelwood and crop residues) within a single framework. This approach enables us to analyze the transition pattern of energy consumption in rural areas from non-commercial to commercial energy and identify the corresponding crucial determinants. Furthermore, we can systematically examine which type of renewable energy technologies is more effective than the others by computing coal equivalent measurement.

We have obtained three important results. First, per capita income is a key determinant in household energy choices. More interestingly, we identify a concave effect of per capita income to per capita coal consumption, which reflects the key role of per capita income in further energy transition.[2] Second, coal and LPG prices have a direct effect on their own energy consumption, but no effect on the substitutes. Finally, in sharp contrast with the findings of Chen et al. (2006), this paper finds that the implementation of some renewable energy technologies has been empirically shown to be outstanding.

Overall, our results suggest a positive perspective over energy transitions that may happen in rural China. If the Chinese government continuously supports the renewable energy technologies, and appropriately design the policies associated with the related energy price controls, then coal consumption will be more induced to decline in the near future. Furthermore, the substitutions to cleaner energy use will speed up. This implies that the smooth energy transition in rural China can be made in more environmentally sustainable manners.

This paper is organized as follows. Data description, and sample data selection procedure are described in Section 2. The empirical specification of the model is discussed in Section 3. Section 4 focuses on the estimation results and interpretation. Finally, conclusions and policy implications are provided in section 5.

2 Data description

2.1 Survey data

The survey data in this study covers the following ten suburban districts in Beijing: Huairou, Miyun, Yanqing, Mentougou, Changping, Pinggu, Shunyi, Fangshan, Daxing and Tongzhou. These districts can be categorized into three groups regarding the geography and social economic level, i.e. the plain, hilly and mountainous districts. Miyun, Huairou, Yanqing and Mentougou are located in the mountainous areas with lowest population density. Changping,

[2] Coal is the low-grade commercial energy resource; further energy transition means the transition from coal to high-quality energy resource.

Pinggu and Fangshan are located in the hilly/plain areas. Tongzhou, Daxing and Shunyi are located in the plain areas with high population density.

Eight hundred households were randomly selected and have been interviewed on energy consumption, demographic characteristics, income, commercial energy price and adoption of energy efficient technologies in July 2009. The reference period in the survey is of year 2008. Forty-four interviewed questionnaires cannot be considered effective since they include missing observations on energy consumption; seven hundred and fifty-six sample sizes have been processed to the dataset.

2.1.1 Socio-economic characteristics

Table 1 provides an overview of socio-economic characteristics of surveyed households. On average, households in the plain districts exhibit their obvious advantages in household-related characteristics: household size, labor force and mid-education.[3] In general, 2.05 out of 3.84 persons per household have received education from junior high school to high middle school. The average labor force per household is 2.83 persons. On average, per capita income in the plain districts is the highest, while that in the mountainous districts is the lowest. Households in the hilly districts have higher per capita income compared to the mountainous district, but rank lower than the average of the total samples. The average LPG price in the mountainous districts is the highest, while that in the plain districts is the lowest. However, the average coal price does not exhibit much variation among these districts.

2.1.2 Per capita energy use

An overview of per capita energy use of the surveyed households is shown in Table 1. On average, households in the mountainous districts consume the largest amount of per capita coal, fuelwood and crop residues, but the smallest per capita LPG. The largest amount of per capita LPG is consumed by households living in the plain districts. Households in the

[3] Labor force is defined as the persons aged between 15 and 60 years and mid-education is defined as the number of persons educated from junior middle school to high middle school

hilly districts consume the largest amount of per capita electricity.

The use of different energy resources of the interviewed households in their daily life is given in Table 2. Except for the purpose of cooking and space heating, electricity is also the energy resource for the operation of electric appliance and lighting. Fuelwood and crop residues are collected by households from their own forestland and farmland, and used for cooking and winter space heating. Coal can be used for cooking, while it is mainly used for winter space heating in the survey districts. LPG can only be used as cooking resource.

2.1.3 Environmental-friendly technologies

Table 3 provides a brief overview of seven environmental-friendly technologies installed in the surveyed households. Adoption rates of the technologies in total samples show that S1 is the highest, while W1 is the lowest. Households living in the plain districts have the highest adoption rate for S2, S3, B2 and B3. Furthermore, B1 is adopted by most households living in the hilly districts.

Table 4 provides a brief summary about the function of seven environmental-friendly technologies covered in the survey. S1 is installed in the streets close to peasants' houses to provide lighting to the public. S2, W1 and S3 are mainly used for improving building energy efficiency and reducing the traditional energy demand for winter space heating. B1, B2 and B3 are used for supplying cooking resources to peasants' households. B2 can also support the households for lighting purpose.

2.2 Beijing's energy consumption structure

For consistent measurement, we convert the unit of consumptions in these five energy resources into kilogram of coal equivalent (kgce). Table 5 provides the conversion factors from physical unit to coal equivalent of five energy resources covered in this study. After taking the average value for each energy resource by using 756 data, we convert the unit of each average value into kgce, and the measurement clearly captures the situation of Beijing's rural energy consumption structure, which reflect the facts shown in Figure 1. Commercial energy totally accounts for 89% while traditional biomass energy only accounts for 11%. Among the commercial energy, coal plays the leading role in residential energy consumption with its proportion of 73% of total energy use. Electricity and LPG are comparatively lower with proportion of 8% separately. For the traditional biomass use, fuelwood accounts for 9%, while crop residues are only 2%.

3 Empirical specification

The purpose of this study is to analyze the determinants of energy choices in Beijing's rural households. This study covers five dependent variables: Quantity of per capita consumption of coal (q_{CO}), electricity (q_E), LPG (q_L), fuelwood (q_{FW}), and crop residues (q_{CR}). Following Chen et al. (2006), we use a non-separable household model, and apply reduced-form equations for five dependent variables. The reduced-form equations for these variables are:

$$\left.\begin{array}{c} q_{CO} \\ q_E \\ q_L \\ q_{FW} \\ q_{CR} \end{array}\right\} = f(T^a, I, P_c, P_l, D^c, H^a) \quad (1)$$

where Tobit regressions are applied in all the five equations to deal with zero values for each energy resource in the data set.

The focus of this study is to examine effectiveness of seven different kinds of environmental-friendly technologies in the consumption of both commercial and non-commercial energy. These renewable energy technologies (T^a) are set as seven dummy variables. Household characteristics (H^a) are represented by household size, household labor force and the number of household members educated from junior high school to high middle school. Per capita income (I) is defined as the ratio of total income per year to household size. Price of coal

(P_c) and LPG (P_l) are the average purchasing prices, respectively. District dummy variables (D^c) are represented by the mountainous and hilly districts. Households living in Miyun, Huairou, Yanqing and Mentougou districts are categorized into the mountainous districts; Households living in Changping, Pinggu and Fangshan districts are categorized into the hilly districts. As the base group, households living in Tongzhou, Daxing and Shunyi are classified into the plain districts.

Table 6 shows the expected signs of the variables used in the regression analysis. Household size is expected to have a negative effect on per capita energy use. The ratio of labor force to household size may have either positive or negative effect on per capita energy use. Similarly, the ratio of mid-educated numbers to household size may positively or negatively affect the per capita energy use.

As the per capita income increases, per capita consumption of electricity and LPG are expected to increase, but the per capita use of crop residues and fuelwood may be decreased. The impact of the per capita income to per capita coal consumption may be unclear. For the households with lower per capita income or equipped with traditional radiator relying on burning coal to heat the house, the increase of per capita income may have a positive effect on per capita coal consumption; while for the households with higher per capita income that can afford adopting other types of winter heating system, i.e. air-conditioning and renewable heating technologies, the increase of per capita income may reduce their per capita coal consumption.

Energy prices should have a direct effect on energy demand. Coal price is expected to have a negative effect on per capita coal consumption, but may have either positive or negative effect on other energy use. LPG price is expected to have a negative effect on per capita LPG consumption, but may have either positive or negative effect on other energy resources. Household electricity price in Beijing is uniform, so we ignore this factor in our regressions. The price of fuelwood and crop residues is zero, and they are regarded as free goods in the market.

Adoption of S1 is expected to reduce household per capita electricity use, considering the fact that Beijing is a place that usually has a very hot summer. With the adoption of S1, people may voluntarily organize some entertainment activities outside at night that may attract many people to join, which directly decrease their indoor activities and thus decrease per capita electricity use simultaneously. S2, S3 and W1 are expected to reduce per capita consumption of coal, fuelwood and crop residues for space heating. Adoption of biomass technologies, i.e., B1 and B2 are expected to decrease per capita consumption of all five energy resources for cooking purpose. Household possession of B3 can reduce per capita consumption of coal, electricity and LPG consumption for cooking purpose, but may increase the per capita use of crop residues and fuelwood, because both of these two biomass resources can be used as burning resource in B3.

4 Regression results

Table 7 reports the regression results for the per capita consumption of commercial energy resource. Table 8 shows the regression results for the per capita consumption of non-commercial energy resources. Tobit models are applied in all the five equations to address the problems of zero values in each dependent variable. The results are interpreted following the order of income-related variables, price-related variables, household-related variables, geographical variables and environmental-friendly technology variables.

4.1 Income impact on per capita energy consumption

Per capita income generally has a significant positive impact on per capita consumption of commercial energy (coal, electricity and LPG), but a negative effect on per capita consumption of crop residues. This proves that per capita income is the key determinant for the change of household energy choices. When per capita income increases, household energy consumption tends to transit from non-commercial energy to commercial energy. This regression result provides strong evidence to the evolution of China's energy consumption structure. With the development of social economic growth, proportion of commercial energy consumption in China has kept increasing, whereas traditional energy use has kept decreasing. This finding is in line with the result in Zhou et al. (2008).

To test the non-linearity relationship between per capita income and per capita energy consumption, squared per capita income variable is applied. The coefficient exhibits a concave effect of per capita income to per capita coal consumption (See the "coal regression" in Table 7 and the coefficient on the squared term is negative.); and the turning point occurs at the per capita income level of 16,625 Yuan. To further estimate the specific year to reach this income level, we take the average value for per capita income growth rate of recent five years from 2005 to 2009 in Beijing's rural districts, which is 10.82% (National Bureau of Statistics of China (2008)). Keeping this growth rate constant in the future years, and based on the 2009 average per capita income of 11,986 Yuan in Beijing's rural households, per capita coal consumption is estimated to reach its maximum level in 2013. This implies that further energy transition from coal to other high-quality commercial energy resources shall be achieved in the future.

Although a concave effect of per capita income to per capita use of electricity and LPG is also estimated in our analysis, these do not have meaningful significance. This may be due to the fact that the turning points are too high to be achieved within useful economic time scales, and few observations of per capita income in our data surpass the peak values of the turning point for electricity and LPG, separately.[4]

4.2 Price effect on per capita energy choices

An increase in coal price is associated with a significant decrease on per capita coal consumption, but it does not have effect on the substitute energy resources. In Beijing's rural areas, coal can be used for both cooking and space heating, and its alternative energy can

[4] The turning point for electricity is achieved when per capita income is 34,850 Yuan. The turning point for LPG is achieved when per capita income is 32,500 Yuan.

be fuelwood, crop residues, electricity, LPG or renewable energy. According to the change of coal price, people may have different action on alternative energy choices due to the distinction between income level, consuming custom and energy resources. Therefore, it may be difficult to find the general tendency in this aspect.

Likewise, an increase in LPG price significantly leads to a decrease of per capita LPG consumption, but it does not show any effect on other energy resources. This is because there are many substitutes for LPG which are accessible and available in Beijing's rural households. More specifically, electricity, fuelwood, coal and crop residues and renewable energy can be regarded as the alternative energy to LPG. Therefore, a change in LPG price may not lead to a change in the demand for a particular substitute.

4.3 Effect of household-related variables

The results display that household size has a significant negative impact on per capita consumption of all these five types of energy resources. Holding the household aggregate energy use constant, households with larger numbers of people afford smaller per capita energy use. Jiang and O'Neill. (2004) argue that find that the household size is another key determinant to energy demand and it is confirmed in almost all the studies. Our results are generally consistent with the previous literature and particularly provide the same evidence with Sheinbaum et al. (1996). They also find that household size in Mexico is quite important in determining per capita energy demand between 1970 and 1990, and its increase leads to a decline per capita energy consumption.

The ratio of mid-educated household numbers to household size has a positive impact on per capita consumption of coal and LPG, but a negative impact on per capita consumption of crop residues. This result reflects that households with more mid-educated people tend to consume more commercial energy than non-commercial energy; and this proves that an increase in mid-educated people per household plays an important role in the change of energy choices in rural China. Since the resumption of university entrance examination in

1977, as well as the implementation of nine-year compulsory education in 1986, mid-educated group has been growing up dramatically in China. Accordingly, energy transition in rural areas has also experienced great changes from non-commercial energy to commercial energy during this period.

Our results can also be supported by other studies. For instance, Demurger and Fournier (2006) find that average education level of adult numbers negatively affects fuelwood consumption, but positively affect use of coal. Farsi et al. (2007) also finds that a head of households with primary or lower education increases the probability of choosing the firewood as cooking resources, whereas a head of households with higher levels of education is more likely to use LPG. However, the difference between their findings and this study is that the ratio of mid-educated household numbers to household size does not show a significant effect on per capita fuelwood consumption. A possible reason may be that except for the cooking purpose, fuelwood can also be used for space heating; however, mid-educated people may not change their traditional heating system from Chinese Kang to other types of heating system after the education.[5]

The ratio of labor force to household size is negatively related to per capita consumption of coal and fuelwood. Labor force in rural areas refers to both on-farm and off-farm labor force. Therefore, an increase in the labor force per household is associated with a decrease in the number of people per household staying at home since most of them would be involved in economic activities which are usually outside of their home. Accordingly, their energy demand for both cooking and space heating decreases. However, this does not necessarily mean that these households tend to change their way of cooking or space heating from use of coal and fuelwood to high-quality energy resources.

[5] Chinese Kang is one of the traditional heating systems in northern China, relying on burning fuelwood or crop residues.

4.4 Geographical variables' impact on per capita energy use

Significant coefficients on the dummy variable for the mountainous districts suggest that households in the mountainous districts consume more electricity, fuelwood and crop residues but less LPG compared to households in the plain districts. This is caused by the fact that both fuelwood and crop residues are free goods in the market, and the mountainous areas are rich in these two energy resources; therefore, households in these districts may prefer to consume more fuelwood and crop residues than LPG for cooking purpose.

4.5 Evaluation on seven technologies

4.5.1 Evaluation on seven technologies for each energy resources

Households living in the villages with S1 significantly consume less per capita electricity by 0.26 KWh per day. This impact indicates that S1 is an effective and environmental-friendly technology. One possible explanation for this is that people increases outdoor activities at night, such as dancing, physical exercise or chatting. These outdoor amusements are usually happening in hot summer. When they are not at home, the electricity used for the electric appliance, such as television, air-conditioning or electric fans will be saved. In addition, most of Beijing's rural peasants are living in a flat house with a court outside. If the court is bright enough at night because of the availability of S1, it is unnecessary for them to open their own lights when they are going out.

Adoption of S2 significantly reduces per capita consumption of coal and electricity by 0.62 kg and 0.33 KWh per day, respectively. This effect implies that S2 contributes prominently to household building energy efficiency improvement on winter space heating.

Households living in S3 reduce their per capita consumption of coal and fuelwood, but increase their per capita consumption of electricity. Because of this mixed impact, we could not give the evaluation of S3 through this result. S3 shows its effectiveness by significantly reducing the coal and fuelwood use for the purpose of winter space heating. However, households living in S3 increase their per capita electricity consumption by 0.28 KWh per day. A possible explanation is that people tend to purchase more of electric appliance, living in the new house with clean living environment. Therefore, they are more motivated to have a better life by purchasing different functional electric appliance.

The most surprising result is that, adoption of W1 does not reduce any type of energy consumption. One possible explanation is as follows: regardless of the adoption of W1, some certain amount of energy such as coal is needed to maintain the initial in-house temperature. After the adoption of W1, the in-house temperature will be improved by the effect of the insulation materials with the energy consumption for coal or other energy resources unchanged. However, once the households get used to such improved temperature, they may keep using the same amount of energy as before. Simply, we conjecture that the most of the households who adopted the W1 in our survey prefer and enjoy the improved temperature than the initial one without changing the energy consumption.

Adoption of B1 significantly reduces the per capita energy consumption of electricity, LPG and fuelwood. This result proves its strong advantages in reducing per capita energy use for cooking purpose. Furthermore, operation of B2 in the households significantly reduces per capita LPG use, which again suggests its effectiveness on the aspect of cooking purpose.

Possession of B3 significantly reduces per capita LPG consumption, but increases the per capita fuelwood use by 0.75 kg per day. The reason for the increase of fuelwood use may be that compared to low-thermal efficiency through direct burning in traditional fuel stove, biomass stove can completely burn fuelwood and improve indoor air quality by diminishing dust emission with some special design. Therefore, for Beijing's rural households who never use fuelwood, this technology may attract them to use it by adopting B3.

In summary, among solar-related technologies, S2 and S3 are the effective technologies to reduce the per capita coal consumption. All the three biomass-related technologies (B1, B2, and B3) play important role in reducing the LPG use for cooking purpose.

4.5.2 Evaluation of seven technologies on aggregate energy consumption

To evaluate these technologies on the same basis and examine their contribution to aggregate energy use, we convert the unit of regression coefficients of seven technologies to kilogram of coal equivalent (kgce). We then sum up the significant coefficients of each technology to obtain their roles in the change of aggregate energy consumption (See Table 9). For instance, we cannot directly tell that S3 is good or bad directly from the Tobit regression results. However, if we calculate the coal equivalent measurement, this can be judged based on the criteria of energy efficiency.

The results reveal that except for W1 and B3, all the other technologies are effective and contribute to, more or less, a decrease of per capita energy consumption in Beijing's rural areas. These results are in sharp contrast with the findings of Chen et al. (2006). More specifically, S2, S3 and B1 exhibit prominent contributions to the reduction of per capita aggregate energy demand. Particularly, S3 shows its strongest contribution to the reduction of aggregate per capita energy demand for 1.34 kgce per day when adopted.

5 Conclusion

This paper has examined the energy consumption of households by utilizing the survey data in rural Beijing areas. To our knowledge, this is the first paper to examine the key determinants of household energy choices involving (i) both commercial and non-commercial energy use and (ii) Beijing's ten rural districts of high variation with respect to socio-economic levels, geographical characteristics and energy consumption patterns. Furthermore, we also conducted the economic evaluation of seven different new technologies promoted in Beijing's rural area based on the estimated energy demand functions.

First, this paper finds the leading role of income levels to the transition of energy consumption structure that have occurred in rural China. Our results further identify some potential concave effect of per capita income to per capita coal consumption. This result provides important reference for policy-makers. That is, with the assumption of per capita income growth rate as 10.82% annually in Beijing's rural households, coal consumption will reach its maximum level within three years, and tend to be transited to other high-quality commercial energy.

Secondly, we also find that coal and LPG prices directly determine their own per capita energy use, but do not show any substitution effect on other energy use. We conjecture that this is mainly caused by the fact that rural residential energy consumption types in Beijing is considerably diversified; people can have different action on alternative energy choices due to the high variations in income level, consuming custom and energy resources. Therefore, we could not draw the general substitution effect in their energy choices corresponding to the change of price.

Finally, the most important conclusion is that the implementation of public renewable energy policies and projects in Beijing's rural area has been empirically proven to be outstanding, which is opposite to Chen et al. (2006). S1 prominently contributes to the target of "Lighting the villages." Among three involved "Warming peasants' house" technologies, S2 and S3 effectively save household per capita coal consumption. For the target of "Recycling the agricultural wasted resources," B1, B2 and B3 have strong effects in reducing per capita LPG consumption by fully utilizing the wasted agricultural residues. In summary, S2, S3 and B1 exhibit prominent contribution to the reduction of per capita aggregate energy demand, among which S3 is the most effective technology and reduces the largest amount of per capita energy consumption.

Our results suggest several policy implications. First of all, based on our estimation, it is crucial for further stimulation on the economic growth in the rural areas to achieve the goal of diminishing coal demand in the near future. Secondly, as shown in the result, both coal price and the adoption of S2 and S3 have the direct effect on the reduction of per capita coal consumption, therefore, the government can design appropriate policies associated with the coal price control, and simultaneously take measures to promote S2 and S3 to induce more clean energy consumption in the rural areas. For the remote households with highest LPG price and abundant traditional biomass resource, biomass technologies (B1, B2 and B3) should be vigorously promoted due to their effectiveness in reducing LPG use for cooking purpose and making full use of wasted traditional biomass energy resources.

Overall, our research suggests a positive perspective over energy transitions that may happen in rural China. If the Chinese government continuously support the effective renewable energy technologies, and appropriately design the policies associated with the related energy price controls, then coal consumption will be more induced to decline in the near future. Furthermore, the substitutions to cleaner energy use will speed up. This implies that the smooth energy transition in rural China can be made in more environmentally sustainable manners through the promotion of renewable energy technologies.

Although we believe that this paper provides very important policy implications on energy transition and its current status, there are several limitations. For instance, we employed only cross-sectional survey data to evaluate the seven technologies. This means that we ignore some dynamic change of energy demands for a single household over time. Thus, future research can be further developed by collecting two period or multi-period panel data which contains the information before and after the adoption of the technologies with the same household. This type of study shall be more valuable to characterize the energy demand in more details.

6 Appendix

In this appendix, we give the detailed definitions of seven renewable energy technologies..

Solar street lights (S1) refers to solar street lights that are installed in the rural streets for lighting the public area at night by utilizing solar energy. Most of S1 are installed close to the peasants' house so that they can enjoy the lighting and lead more colorful life at night.

Solar heating system (S2) is a technique that can convert sunlight into heat resource in the house. S2 can consist of a passive system, an active system, or a combination of both. Active solar space-heating systems consist of collectors that absorb solar radiation combined with electric fans or pumps to transfer and distribute that solar heat. Passive solar space heating takes advantage of warmth from the sun through design features, such as large south-facing windows, and materials in the floors or walls that absorb warmth during the day and release that warmth at night when it is needed most.

Energy-efficient new house (S3) is the newly built eco-house equipped with solar panels to utilize solar energy for space heating or hot water supply, and simultaneously adopt new building materials which is excellent in heat insulating property. S3 is characterized by the integration of solar technologies and building energy efficiency.

Building energy efficient retrofits (W1) is the retrofit of existing residential houses which are high energy consumption buildings by adopting new building materials in the envelopes. Insulation is an important method of retrofit. As usual, insulation of external wall and roof are preferential measures of such many measures that improving the thermal properties of envelops. Due to the distinction in income level and building structure, in Beijing's rural area, except for the retrofit of external wall and roof, insulation of window is another way to improve the thermal comfort of the house.

Biomass gasification and gas-supply system (B1) works by gasifying the biomass resources such as agricultural residues into fuel gas, which is supplied to households through pipes from gasification station to households for cooking, space heating or other purpose. B1 in this paper is only used for supplying gas resource for cooking purpose.

Household anaerobia digesters (B2) can produce biogas through unitizing energy crops such as maize silage or biodegradable wastes including sewage sludge and food waste. During the process, an air-tight tank transforms biomass waste into methane and produces biogas that can be used for cooking or lighting.

Biomass stove (B3) refers to the improved traditional biomass stove that can completely burn the fuelwood and crop residues and improve indoor air quality by diminishing the dust emission with some special design. Compared to the traditional biomass stove, B3 is a kind of environmental-friendly stove which is good to both human health and environment and can make full use of wasted agricultural residues.

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Figure 1: Beijing's energy consumption structure

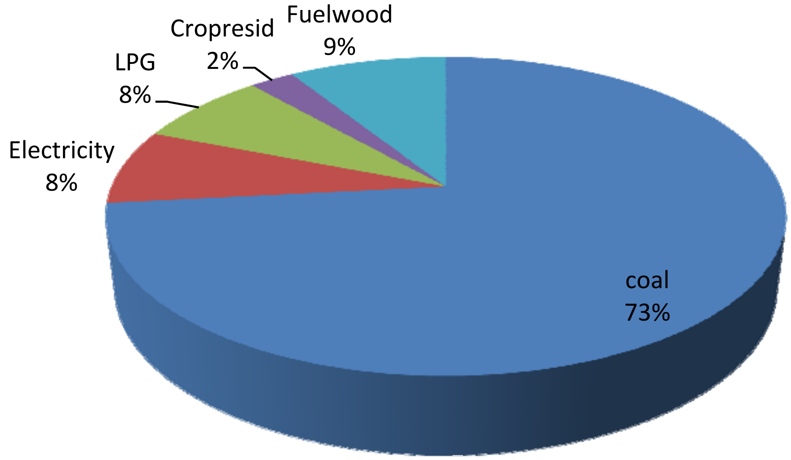

Table 1: Socio-economic characteristics and per-capita energy use of the surveyed households

	Plain districts	Hilly districts	Mountainous districts	All districts
socio-economic characteristics				
Household size (persons)	4.02	3.73	3.81	3.84
Labor force (persons)	3.2	2.78	2.64	2.83
Mid-education (persons)	2.18	1.96	2.04	2.05
per capita income(one year)(Yuan[a])	6444	4793	4764	5188
average coal price (Yuan[a]/kg)	0.9	0.89	0.94	0.92
average LPG price (Yuan[a]/kg)	3.82	4.73	5.27	4.7
per capita energy use				
Coal consumption (kg/day)	1.8	1.82	1.86	1.83
Electricity consumption (KWh/day)	0.9	1.23	1.07	1.07
LPG consumption (kg/day)	0.12	0.07	0.06	0.08
Fuelwood use (kg/day)	0.09	0.22	0.55	0.33
Crop residues (kg/day)	0.04	0.02	0.19	0.1
sample size	198	240	318	756

[a] 1 Yuan = 0.15 US Dollar (at the time of survey)

Table 2: Use of different energy resources for surveyed households

Lighting	Electricity
Space heating	Coal
	Fuelwood
	Crop residue
	Electricity
Cooking	LPG
	Coal
	Fuelwood
	Crop residue
	Electricity
Electric appliance	Electricity

Table 3: Installed number for seven technologies of the surveyed households

	Plain districts	Hilly districts	Mountainous districts	All districts
solar street light (S1)	128	118	181	427
solar heating system (S2)	27	10	9	46
energy-efficient new house (S3)	29	6	5	40
building energy efficient retrofits (W1)	8	11	11	30
biomass gasification and gas-supply system (B1)	7	27	12	46
household anaerobia digesters (B2)	20	17	20	57
biomass stove (B3)	31	24	8	63
sample size	198	240	318	756

Table 4: Function of each environmental-friendly technologies installed in surveyed households

	Technologies
Lighting	solar street light (S1)
	household anaerobia digesters (B2)
Space heating	solar heating system (S2)
	building energy efficient retrofits (W1)
	energy-efficient new house (S3)
Cooking	biomass gasification and gas-supply system (B1)
	household anaerobia digesters (B2)
	biomass stove (B3)

Table 5: Conversion factors from physical Unit to coal equivalent

Energy type	Unit	Conversion factor (kgce/unit)	Average Low Calorific Value (kjoule/unit)
Coal	kg	0.7143	20,908
Electricity	KWh	0.1229	3 596
LPG	kg	1.7143	50,179
Fuelwood	kg	0.571	16,726
Crop residues	kg	0.529	15,472

Table 6: Expected signs of variables used in the regression analysis

Independent variable	Dependent variables (per capita energy use)				
	Coal	Electricity	LPG	Fuelwood	Crop residues
Household size	—	—	—	—	—
Mid-education/household size	+/—	+/—	+/—	+/—	+/—
Labor force/household size	+/—	+/—	+/—	+/—	+/—
per capita income	+/—	+	+	—	—
Coal price	—	+/—	+/—	+/—	+/—
LPG price	+/—	+/—	—	+/—	+/—
Solar street light(S1)		—			
Solar heating system (S2)	—	+/—		—	—
Energy-efficient new house (S3)	—	+/—	/	—	—
Building energy efficient retrofits (W1)	—	+/—	/	—	—
Biomass Gasification and Gas-supply system (B1)	—	—	—	—	—
Household anaerobia digesters (B2)	—	—	—	—	—
Biomass stove (B3)	—	—	—	+	+

Table 7: Tobit regression results for per capita consumption of commercial energy in survey districts

Variables	Coal	Electricity	LPG
	Parameter[a]	Parameter[a]	Parameter[a]
Constant	3.16***	1.20***	0.16***
	(7.65)	(4.97)	(7.26)
Per capita income	0.133***	0.0697***	0.0065***
	(4.61)	(4.27)	(4.55)
(Per capita income)^2	-0.004***	-0.001*	-0.0001***
	(-4.05)	(-1.79)	(-3.20)
Coal price	-0.757***	0.12	0.0032
	(-3.38)	(0.95)	(0.27)
LPG price	0.0005	-0.0023	-0.013***
	(0.01)	(-0.08)	(-5.00)
Household size (HS)	-0.26***	-0.155***	-0.01***
	(-5.60)	(-5.74)	(-3.85)
Mid-education/HS	0.46**	0.15	0.043***
	(2.40)	(1.30)	(4.08)
Labor force/HS	-0.67***	-0.14	-0.01
	(-3.01)	(-1.08)	(-0.51)
Mountainous districts	0.06	0.25**	-0.048***
	(0.34)	(2.36)	(-4.99)
Hilly districts	-0.02	0.44***	-0.047***
	(-0.1)	(4.12)	(-4.96)
S1	—	-0.26***	—
	—	(-3.38)	—
S2	-0.62**	-0.33**	—
	(-2.23)	(-2.06)	—
S3	-0.572**	0.28*	—
	(-1.96)	(1.69)	—
W1	0.46	0.02	—
	(1.44)	(0.09)	—
B1	-0.20	-0.34**	-0.03**
	(-0.76)	(-2.17)	(-2.21)
B2	-0.05	0.07	-0.031**
	(-0.21)	(0.49)	(-2.37)
B3	-0.07	0.02	-0.025*
	(-0.28)	(0.18)	(-1.95)

[a] t-value in parentheses

*Significant at 10% level

**Significant at 5% level

***Significant at 1% level

Table 8: Tobit regression results for per capita consumption of non-commercial energy in survey districts

Variables	Fuelwood	Crop residues
	Parameter[a]	Parameter[a]
Constant	-0.07	-0.17
	(-0.14)	(-0.52)
per capita income	-0.04	-0.079***
	(-0.97)	(-3.15)
(per capita income)^2	-0.0002	0.001
	(-0.19)	(1.17)
Coal price	0.15	-0.06
	(0.56)	(-0.33)
LPG price	-0.04	0.02
	(-0.71)	(0.51)
Household size (HS)	-0.11*	-0.062*
	(-1.91)	(-1.65)
Mid-education/HS	-0.33	-0.72***
	(-1.37)	(-4.58)
Labor force/HS	-0.46*	0.19
	(-1.74)	(1.08)
Mountainous districts	0.87***	0.44***
	(3.69)	(2.86)
Hilly districts	0.22	-0.32*
	(0.96)	(-1.93)
S1	—	—
	—	—
S2	0.06	0.14
	(0.16)	(0.6)
S3	-1.80***	-0.53
	(-2.96)	(-1.55)
W1	0.39	-0.10
	(0.98)	(-0.35)
B1	-0.85**	0.10
	(-2.30)	(0.49)
B2	0.03	-0.34
	(0.1)	(-1.45)
B3	0.75***	0.13
	(-2.73)	(0.67)

[a] t-value in parentheses

*Significant at 10% level

**Significant at 5% level

***Significant at 1% level

Table 9: Aggregate energy impacts for seven technologies to per capita consumption of five types of energy resources

Variables	Per capita energy consumption					Aggregate changes[b] (kgce/day)[a]
	Coal (kgce/day)[a]	Electricity (kgce/day)[a]	LPG (kgce/day)[a]	Fuelwood (kgce/day)[a]	Crop residues (kgce/day)[a]	
Solar street light (S1)	—	-0.09***	—	—	—	-0.09
Solar heating system(S2)	-0.44**	-0.12**	—	0.03	0.07	-0.56
Energy-efficient new house (S3)	-0.41**	0.10*	—	-1.03***	-0.28	-1.34
Building Energy Efficient Retrofits(W1)	0.33	0.0059	—	0.22	-0.05	—
Biomass Gasification and Gas-supply system(B1)	-0.14	-0.12**	-0.055**	-0.49**	0.053	-0.665
Household anaerobia digesters(B2)	-0.04	0.025	-0.054**	0.017	-0.179	-0.054
Biomass stove (B3)	-0.05	0.009	-0.043*	0.426***	0.066	0.383

[a] (kgce/day): kilogram of coal equivalent (convention factors are listed in Table 5.)

[b] Aggregate changes: aggregate energy impact of each technology by summing up their significant coefficient in the five equations