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Electricity Demand and Basic Needs: Empirical Evidence from China's Households

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Abstract <An increasing block tariff (IBT) has been implemented nationwide in the residential sector in China since July 2012 as part of a process towards liberalizing electricity prices. However, knowledge about IBT design is still limited, particularly how to determine the electricity volume for the first block of an IBT scheme. Assuming the first block should be set based on some measure of electricity poverty, we attempt to model household electricity demand such that the range of basic needs can be established. We find that in Chinese households there exists a threshold for electricity consumption with respect to income, which might be considered a measure of electricity poverty, and the threshold differs between rural and urban areas. For rural (urban) families, electricity consumption at the level of 7th (5th) income decile households can be considered the threshold for basic needs or a measure of electricity poverty since household electricity demand in rural (urban) areas does not respond to income changes until after the 7th (5th) income decile. Further, for the case of China's electricity consumption, we find that if there is a saturation point, after which household energy needs would not rise further proportionately with increasing income, it is far from having been reached. Whereas the first IBT block was set at 240 kWh per household for Beijing, we estimate basic needs to be roughly 90 kWh per month for rural households and 150 kWh for urban households. The first IBT block therefore appears to have been set at a level that is too high, roughly equivalent to the average consumption of the *top* decile of urban residents. Over time however, given continued rapid growth, the IBT will begin to better reflect actual basic needs. >

Keywords Key Words

JEL Classification N55, P28, Q41, O13, I3

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I. Introduction

Over the past three decades, China's economic growth has driven rapid increases in electricity consumption. Between 1980 and 2012, electricity consumption in China increased from 300 TWh to 4976 TWh, an annual growth rate of 9.2%. Over the same period, electricity demand in the residential sector, accounting for 13.3% of total electricity consumption, grew at an even faster rate of 12.0%.[a] Retail electricity prices are tightly regulated by the Chinese government and have long been kept at artificially low levels (Lin and Jiang, 2011; Lin and Jiang, 2012). Moreover, electricity consumption in the residential sector is cross-subsidized by the industrial and commercial sectors, and retail prices for residential electricity are usually lower than its long-term marginal cost (Lin and Jiang, 2011; Sun and Lin, 2013). Reform towards cost-reflective tariffs has proven difficult because of concerns that increasing prices may impact the welfare of poor households and, as such, electricity prices are politically sensitive. Whereas electricity prices are subject to strict controls, the coal price has been liberalized since 1992. As a result, any cost increases borne by electricity producers could not be simply transferred to end users because of price controls (Wang, 2007; Ngan, 2010). The twin-track prices for coal and electricity have led to conflicts between the two industries and supply disruptions in many districts (Ming et al, 2013; Mou, in press;).

Given the untenable situation, the Chinese government has begun to promote electricity price reforms. One reform measure is the increasing block tariff (IBT), which has been implemented nationwide in the residential sector since July 2012, so as to eventually reduce electricity cross subsidies and promote efficient use of electricity. IBT, a nonlinear pricing method comprising a rising set of charges as consumption increases, has often been promoted as a solution to address social equity, cost recovery, efficiency, and/or environmental concerns (Borenstein, 2012). The nonlinearity of IBT implies that the expenditure on electricity is not linearly proportional to

[a] Calculated by the authors based on original 2013 data found in NBS (2014).

consumption. IBT has been used not only for electricity, but in the case of China and other developing countries, IBT has been used for regulating water tariffs (Banerjee et al., 2010). Under an IBT scheme, household electricity consumption can be divided into several blocks, and a prescribed price applied to each defined block. In theory, IBT has the capability of achieving economic efficiency and social equity simultaneously while enabling cost recovery by utilities. However, in practice, its impact depends largely on the details of the scheme. For example, a large volume of electricity in the initial block with a subsidized price might result in excessive subsidies. Although IBT has been the subject of considerable attention recently in China, knowledge about IBT design is still limited, particularly how to determine the rate and the electricity quantity for the first block of an IBT scheme.

In developing countries， the first block of IBT has usually been set at a subsidized price, with a nominal goal of ensuring the poor can afford to pay for some minimum volume of energy services to perform such basic tasks as cooking, lighting and heating at an affordable price (usually described as a "lifeline" tariff). Lifeline rates are a type of inverted rate[a] that price some initial block or amount of electricity below the cost of production (Hennessy, 1984). The philosophy behind lifeline rates is that electricity is a necessity in modern society and every family should be able to purchase enough electricity to meet its minimum needs without undue budgetary stress (Petersen, 1982). Many studies focus on the effectiveness of "lifeline" subsidies using IBT. For Kuwait, Al-Qudsi and Shatti (1987) indicated that the government's proposed lifeline rate structure was viable from the perspectives of equity, conservation and efficiency. However, Estache, Foster and Wodon (2002) suggested that lifeline subsidies for electricity consumption in Guatemala and Honduras involved large errors of inclusion because the consumption ceiling to benefit from the subsidy was set too high. It is obvious that the ability of the IBT to deliver social equity on its promise of effectively targeting the poor depends on setting the volume of electricity in the initial block equal to the basic electricity needs. If

[a] Inverted rates (IR) usually consist of two or more blocks that are priced at increasingly higher levels, see Neufeld and Watts (1981) and Dimopoulos (1981).

a high volume be set, wealthier households would get more benefits from the low price. If it is the case that "every family should be able to purchase enough electricity to meet its minimum needs", one empirical question concerning IBT is to model the household electricity demand such that the size of the minimum-need block can be established.

Based on a dataset drawn from a survey of three provinces in China, we estimate the electricity demand of rural and urban households, attempting to define and quantify their basic electricity needs. Having controlled of the variables that could affect electricity consumption of households, we define the minimum quantity of electricity of the households, using the measurement for "energy poverty" developed by Khandker et al (2010). To our knowledge, no study has examined the basic electricity needs of households in China. To be specific, the first studies of IBT in China have mostly set the electricity volume of each block at a pre-determined level, rather than basing it on a quantitative analysis (e.g., Lin and Jiang, 2012; Sun and Lin, 2013). Lin and Jiang (2012) suggested setting the first block in the IBT scheme based on the "lifeline volume", and setting the second block to meet the "basic demand" of low-income households. In defining the lifeline block and basic block respectively as average consumption of "the poorest" and "low income urban" households, they proposed that the threshold for the two blocks be 45 kWh and 80 kWh per month per household. However they did not provide their estimation method. In other studies, lifeline rates were usually based on either "essential needs" (Petersen, 1982; Hennessy, 1984) or "basic needs" (Wodon et al., 2003; Komives, 2005).

In our study, we attempt to establish a single measure of basic needs rather than distinguishing between "lifeline" needs and essential (or basic) needs. We provide an estimate of basic needs for electricity in Chinese households in Section 4, but our primary purpose is to provide a conceptual discussion regarding how household electricity demand should be defined and measured. Our results have clear policy implications and provide empirical evidence to help improve the IBT scheme in China. The remainder of our study is organized as follows: in Section 2, we discuss household electricity consumption patterns in China. In Section 3, we present the analytical framework for defining and measuring households' basic needs for electricity, using a demand-based approach and drawing on a definition of "energy poverty". In Section 4, we empirically investigate household electricity consumption in China, specifically how electricity consumption responds to the changes in income.

II. Electricity consumption of Chinese households

Energy consumption patterns (and lifestyles) of Chinese households have changed drastically with rapidly rising income over the past three decades. In the 1980s, China's residential electricity consumption was almost entirely used for lighting. Since the 1990s, however, the use of household appliances has increased rapidly, and recreational activities have played a growing role, particularly in urban areas. Electricity is one of the principal energy sources for recreation and social communication, being used for televisions, computers, DVD players, and audio systems, in addition to more 'basic' forms such as lighting, cooking, washing, cooling and heating. Lin and Jiang (2012) estimated that in the electricity consumption of urban low-income households, electricity used for lights, refrigerators, cookers, electric fans and washing machines respectively accounted for 28%, 28%, 12%, 11% and 4%, and electricity used for recreation accounted for the remaining 18% (only televisions are considered). Though no further information on consumption patterns of other income groups is available, it is reasonable to assume that wealthier urban households would use more electricity for recreation. In rural areas, electricity is used not only for daily life but also for production, such as in home workshops. The energy used for productive activities accounted for more than 50% of rural residential energy consumption over the past twenty years (NBS, 2011a; NBS 2013a), mainly in the form of coal, electricity and diesel. Although exact figures for electricity used as productive input is not available, its proportion in energy consumption of rural families must logically be quite significant.

China's electricity consumption per capita is still much lower than those of developed countries, which implies a huge potential for further growth. Because we will have to use data from 2009 for our econometric analysis in Section IV, the data cited in this section are for 2009 to make it easier to compare, unless otherwise stated. A brief review of the change between 2009 and 2012 is given in Table 1 to illustrate the dramatic increase in electricity consumption in just three years. During this period, total electricity consumption of China increased from 3703 TWh to 4976 TWh, a growth rate of over 10% per annum. The proportion of residential consumption in total electricity consumption has held steady at about 13%, which is much lower than that of industry (about 73%). Meanwhile, in the residential sector, electricity consumption per capita has grown from 365 kWh to 459 kWh (or 8% growth per annum).

Table 1. Changes in electricity consumption in China's households from 2009 to 2012

Year	Total final consumption (TWh)	Final consumption in residential sector (TWh)	Share of resident consumption (%)	Average consumption in residential sector (kWh/capita/year)
2009	3703.2	487.2	13.2	365
2012	4976.3	621.9	12.5	459

Source: calculations based on NBS (2011b) and NBS (2014).

In 2009, per capita residential electricity consumption in rural and urban areas was 296 kWh and 439 kWh, respectively (Table 2). As a share of residential end-use energy consumption, electricity accounts for 25.9%, just behind coal at 29.5% (Figure 1). Obviously, per capita consumption of both end-use energy and end-use electricity is higher in urban areas. In rural areas, coal is still the most popular source of energy because of its availability and convenience, in addition to the low penetration of petroleum products and gas. Most coal is used for home heating in winter, particularly in northern China. The share of coal in energy consumption for rural households is as much as 57.7%, compared to 11.2% in urban areas.

Table 2. Energy and electricity consumption in China's households in 2009 [a]

	End-use energy in residential sector (kce/year/capita)	End-use electricity in residential sector (kWh/year/capita)	Share of electricity in residential end-use energy [b]
National	173	365	25.9%
Urban	218	439	24.8%
Rural	132	296	27.6%

[a] calculated based on China energy statistical yearbook 2010 (NBS, 2011b) and China Rural Household Survey Yearbook 2010 (NBS, 2011a).
[b] based on calorific value calculation.

Per capita electricity expenditure in urban households is estimated to be 125 yuan, which is 0.73% of disposable personal income, while for rural households the per-capita figure is about 83 yuan, or 1.60% of income[a]. In some rural areas, a variety of non-commercial energy sources, such as straw, firewood, biogas and solar, are still popular, mainly for cooking, which is supplemented by commercial energy sources, such as coal, LPG and electricity. Generally speaking, as income levels of rural households rise, the share of commercial energy consumption rises. Luo and Zhang (2008) found that non-commercial energy accounted for 55% of total energy consumed by rural households. They argued that energy consumption per capita of rural households was actually much higher if non-commercial energy were to be included – energy consumption of urban households is only 39% of that of their rural counterparts, according to their estimation.

[a] Figures are calculated based on original data from NBS (2011a), which provides electricity expenditure per urban household, electricity consumption per rural household, and the average population of rural households and urban households. The electricity price used in calculation is the average of provincial prices.

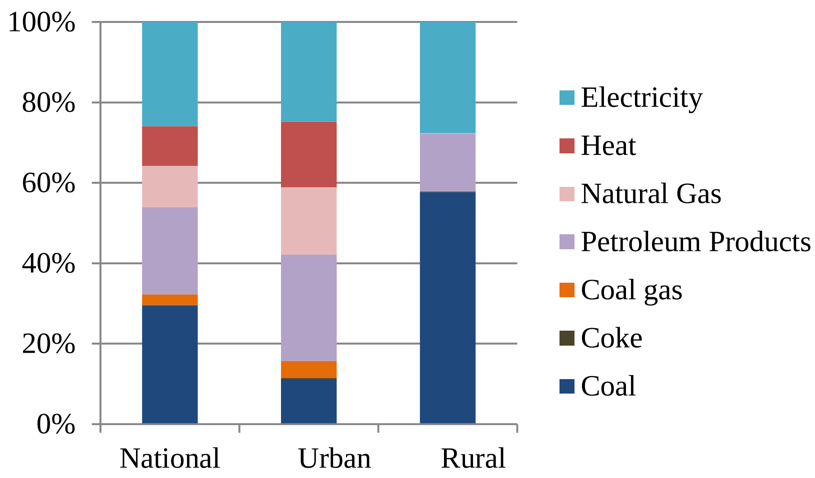

Figure 1. Residential consumption of commercial energy in 2009

III. Methodology

Access to basic energy services is often regarded as a universal human right (Bradbrook and Gardam 2006). Basic needs of households are described as "basically linked to the needs of 'living' at the most general level (Bravo et al., 1983). Parikh (1978) argued that household energy requirements include following basic necessities: the energy required for producing food, for cooking and lighting, and the energy for transporting food and fuels to the people. Though it is generally recognized that energy services are central for the provision of basic human needs, there is no consensus on the amount of energy to meet basic household needs, exactly what should be included nor its extent. Energy needs vary significantly among countries and regions, depending on a number of factors, such as cultural practices, climatic conditions, social customs, subjective wants, and so on.

To be clear, access and poverty are related but distinct concepts and normally, access is just one of several elements of fuel poverty or a precondition for measuring energy poverty. Bhattacharyya and Ohiare (2012) describe how since 1998 access to electricity in rural China has increased via an ambitious program to upgrade rural electricity networks, which helped to halve transportation losses (from 25% to 12%), all of which helped in harmonising electricity tariffs of rural and urban consumers.

Common energy services needed by households include cooking, space heating or cooling, lighting, entertainment or education (e.g., computer), and the services provided by means of household appliances, telecommunications, and mechanical power. Basic needs may be interpreted objectively in terms of minimum specified quantities of goods and services, or subjectively as the satisfaction of consumer wants as perceived by consumers themselves (Streeten, 1984). It is generally agreed that basic energy needs is the minimum needed for subsistence (Parikh, 1978; Krugmann and Goldemberg, 1983; Goldemberg et al., 1985; Ravallion and Bidani, 1994).

The definition of basic energy needs usually has a strong correlation to how the needs are measured. Absent a universally accepted measure of basic energy needs, researchers interpret the required minimum level of energy needs in different ways. Similar disagreements over definitions and metrics can be found in the literature on energy poverty. An energy poverty line specifies a minimum level below which household can be considered “poor” in terms of energy services, and the energy quantity corresponding to the level is regarded as the “basic needs” (Ravallion and Bidani, 1994; Pachauri and Spreng, 2004). Consequently, the notion of basic energy needs in concept is equivalent to the energy poverty and a definition of basic energy needs can be derived from the measure of energy poverty.

Energy poverty is often considered synonymous with fuel poverty. According to Osbaldeston (1984), Isherwood and Hancock were among the first to define fuel poverty in 1978. They defined “households with high fuel expenditure as those spending more than twice the median on fuel, light and power”. Boardman (1991) defined a fuel poor household as one “unable to obtain an adequate level of energy services, particularly warmth, for 10 percent of its income.” Her idea was basically adopted in the 2001 UK Fuel Poverty Strategy (DEFRA and DTI, 2001). The term fuel poverty is usually used in Europe (especially in the UK and Ireland), as it is experienced in industrializing countries and focuses on the issues of affordability. In developing countries, energy poverty is concerned with lack of access to utilities such as heating and electricity, as well as broader aspects of cost (Liddell et al., 2011). Pollitt (2009) derides the term as one that "makes little economic sense" and unnecessarily distortionary when there is an effective system for wealth transfers, but is more sympathetic to the need for price intervention for poor consumers in developing countries where for "unresponsive or poorly developed welfare systems this may be not be an option".

Measuring energy poverty requires both a definition of an energy poverty line, and techniques to measure it (Heindl, 2013; Boardman, 2013). Since the study by Boardman (1991), there have been various attempts to calculate the amount of basic energy need and to define energy poverty. Early studies mostly aimed at estimating basic energy needs on the basis of subjective assessment of what constitute the basic needs. More recent studies have tried to derive an energy poverty line from a conventional income or expenditure poverty measure. Ravallion and Bidani (1994), Pachauri and Spreng (2004) and Khandker et al (2010) separately provide a brief review of the methods that have been used to measure energy poverty. Other studies have focused primarily on analyzing the implementation of existing policies with regard to energy poverty (Bouzarovski, Petrova, and Sarlamanov, 2012).

Broadly speaking, there are two ways to define the energy basic needs, namely a physical quantity approach (or engineering type calculation) and an expenditure method approach.

- **The physical quantity approach**

If basic needs is defined according to the minimum amount of energy demand required for a basket of goods and services, then that is viewed as adopting a physical approach. The calculation, in addition to defining a set of basic needs at the household level, relies largely on a number of assumptions regarding the number and type of energy consuming appliances, their size, efficiency and utilization.

In defining the basic needs required at household level, Bravo et al (1983) suggested that the following energy services be included, in order of importance: a) preparation and preservation of food and supply of water; b) space conditioning; c) personal cleanliness; and d) recreation and social communication. Using the physical quantity approach, Parikh (1978) estimated the energy required for subsistence-level activities in developing countries ranging from 0.3 to 0.4 tce per capita. Krugmann & Goldemberg (1983) and Bravo et al (1983), provided estimates for the energy poverty line ranging from 0.29 tce per capita in hot urban areas to 1.79 tce in cold rural areas. Some studies have taken a fairly wide scope – for example, Nussbaumer et al (2012) define energy poverty according to a multidimensional index, which includes use of modern fuels for cooking, access to electricity/lighting, having a fridge, having a radio or television and having a telephone whether landline or mobile. Others argue for greater consideration of specific goods and services, for example, Sovacool et al (2012). Obviously, the principal disadvantage of any such method is the difficulty in pinning down what are the exact contents of the basket of goods and services, owing to the absence of universally accepted definition of basic needs (Pachauri and Spreng, 2004). Reaching an agreed definition may be even more problematic for the case of electricity than for energy more generally since there is little previous work describing a "right to electricity" in particular. Since any quantification of basic needs is contingent on context (norms, climatic conditions, etc.), there will be variation from region to region and country to country and the definition may even change over time. Energy poverty based on physical quantity analysis is therefore not invariant, indeed, the cutoff point for the energy poverty line is inevitably arbitrary and inconsistent (Barnes et al., 2011).

- **The expenditure based approach**

Adopting an expenditure approach defines basic energy needs by one's financial ability to meet basic needs and accordingly, energy poverty is essentially a form of income poverty. There are two typical ways that expenditure is used to define energy poverty and measure basic needs: the expenditure method and the expenditure share method.

In the expenditure method, energy poverty is defined by the level of energy demanded by households who fall below a prescribed expenditure or income poverty threshold; hence, families that are poor in terms of income are also considered energy-poor. This method is fairly attractive since there is no need to measure how much and what kinds of energy are actually used by individual households; furthermore, income poverty is usually well-defined in most countries and regions (Barnes et al., 2011). One can then simply measure average energy demand for households at the income poverty line and equate that demand with the level of basic energy needs. The idea behind the method is quite clear, the resulting definition of basic need is precise, the data needed is readily available and the measurement technique is relatively simple. The disadvantage, of course, is that it assumes that energy poverty follows exactly the same pattern as expenditure or income poverty, thus the income poor are defined as energy poor regardless of access to energy supply, climatic conditions or societal norms. As Hills (2012) pointed out, income poverty and fuel poverty are not the same, although disentangling the two is by no means straightforward.

The expenditure share method examines the proportion of household income spent on energy. A household is classified as energy-poor if the share of its energy expenditure in income is greater than a specific percentage. The idea here is that households forced to spend a large proportion of their income on energy are deprived of other basic goods and services, and their welfare is therefore reduced. The implied assumption is that poor households spend a higher percentage of their income on energy than wealthier ones. A common value used for the expenditure share threshold is 10% of available income (Fankhauser and Tepic, 2007). According to Hills (2012), this particular threshold appears to "derive from an original calculation that in 1988 the median household spent 5 per cent of its net income on fuel and that twice this ratio might be taken as being unreasonable".

The expenditure share method captures the ability of a household to maintain its current energy expenditure over time without having to increase the share of its budget spent on energy. However, it does not take account of various dynamic effects including changing energy efficiency, price effects, and shifts in real income (Hatfield-Dodds and Denniss, 2008). Many assumptions have to be made to generate the required outputs, and the final result is sensitive to those assumptions and the threshold chosen (Liddell et al., 2011). Similar to the approaches discussed above, to a large extent, it is arbitrary why a number such as 10 percent (Boardman, 1991) or any other preset expenditure ratio is selected. Apart from the question of defining the energy poverty line (as a proportion of expenditure), there are a number of possible ways to measure income and energy costs. Moreover, the share of energy budget in a household's expenditures is often dependent not only on the type of energy used and its market price, but also the efficiencies and the costs of appliances (Pachauri and Spreng, 2004).

- **Energy demand-based approach**

The physical quantity approach and the expenditure-based approach differ in their ability to capture differences in households' energy needs arising from different household characteristics, in their data requirements and in their robustness to changes in energy price. However, they all tend to ignore important criteria and suffer from the similar defect of setting an arbitrary threshold to define energy poverty; hence, the level of basic energy needs obtained is also arbitrary.

The idea of a demand-based approach is that the role of energy use in household welfare should be assessed based on the demand for energy services and not energy expenditures alone. This method seeks to set a threshold at the point energy consumption begins to rise with increasing income. At or below the threshold point, households are consuming what is effectively a minimum level and can be considered energy poor (Liddell et al., 2011).

The "minimum end-use" (MEE) method, proposed by Barnes and his co-authors (Khandker et al., 2010; Barnes et al., 2011), is a specific demand-based method. The threshold is defined as the income decile where household energy consumption starts to respond to changes in income. This definition of energy poverty is similar in concept to the expenditure approach. It is applicable to a wide variety of conditions and overcomes some of the drawbacks of other methods in terms of arbitrariness and inflexibility, since it does not specify a predefined figure as the threshold. Rather, the assessment of basic energy needs is based on the energy demand function, taking into account a range of important exogenous factors.

We use the MEE approach to determine the basic electricity demand of households in China and how it varies with changes in income, after controlling for a number of exogenous variables at the household and district level. The premise for defining a basic level of electricity needs is that there exists a threshold level of electricity that a household must consume in order to maintain a minimum level of welfare, which is independent of its income. More specifically, above that threshold, electricity consumption may be influenced by a variety of influences, including family size, income, prices, preferences, climate and geographical conditions. These factors are likely to be quite different between urban and rural areas and between north and south. However, the relationship between electricity demand and income should be weak for a household that is merely meeting its basic electricity needs.

IV. Empirical analysis

- **Model**

The electricity needed for subsistence varies with region, climate, lifestyle, culture, etc. In an attempt to determine an approximate range of the minimum electricity requirement of households, we investigate how household electricity demand varies with the change in income by estimating an electricity demand function as follows:

$$ln\mathrm{E}_{ij} = \beta_0 + \sum_l \beta_l \mathrm{X}_{\mathrm{ij}l} + \sum_{k=2}^{10} \alpha_k \mathrm{Y}_{\mathrm{decile}_{ijk}} + \varepsilon_{ij} \quad (1)$$

In equation (1), E_{ij}, measured in kWh per capita, is the monthly electricity consumption of household i in district j. $ln\text{E}_{ij}$, the logarithm of electricity consumption, is regressed on the income dummy variables ($\text{Y}_{\text{decile}_{ijk}}$, k=2,3…,10) and a vector of control variables (X_{ij}) that represent the household and district characteristics. ε_{ij} is the unobserved random error and β_0, β_l and α_K are the coefficients to be estimated. Assuming household income is a key determinant in identifying its electricity needs, we use nine dummy variables that categorize per capita income of households by income decile. The income dummy variables represent the income deciles of households and income measured in per capita terms. The control variables consist of: size of household living area; number of household members; age, education level and gender of the head of household; household assets; distance of the household to the nearest local commercial center; local climate of the district, and energy prices. We next describe each of the independent variables in the model in turn.

a. Household income

The indicator Y_{decile} splits the sample into ten categories. Specifically, all observations are categorized by the quantiles of per capita income, using observed values of the income as category cut points. The focus is on the impact of different levels of income on electricity consumption; hence, the threshold of minimum electricity demand by households is defined according to the income decile until which electricity demand keeps insensitive to income changes.

The income indicator is constructed using households' disposable cash income and lagged for one period. An alternative measure for wealth might be to use household expenditure, which is more reflective of long-term income, however, an expenditure measure cannot properly account for the distribution of wealth across households when saving rates are high and unequally distributed (Démurger and Fournier, 2011). Given that insurance and credit markets in China are often absent or imperfect, most Chinese households have limited access to formal insurance mechanisms and consequently have to turn to savings, as reflected by high Chinese saving rates. Therefore in comparison with expenditure, income is a better indicator of household wealth.

b. Household assets

Monetary income does not represent the true level of household wealth, particularly for rural households where self-consumption is common and important. Therefore, in addition to the income dummy variables based on cash income, we introduce household assets to control for the wealth effect on household electricity demand. As a stock indicator, the advantage of assets variables is that they capture the characteristics of wealth accumulation and its different manifestations between rural households and urban ones.

While urban household assets can usually be completely accounted for by non-productive assets, such as real estate, financial assets (e.g. deposits, stocks and securities) and durable goods, the assets of rural households include both non-productive and productive assets (e.g. pasture, farmland and woodland). Further, unlike urban households, rural households in China are rarely involved in financial markets, and their accumulated wealth is reflected in real estate and agricultural machinery.

In what follows, we use different indicators to capture the wealth effect of household assets on its electricity needs. In particular, for urban households, an indicator of financial assets is introduced to measure wealth accumulation; for rural households, an indicator of agricultural land ownership is used to reflect the impact of productive assets on electricity demand.

c. Demographic factors

To control the influence of demographic characteristics on household electricity consumption, four demographic factors are introduced into the model: family size, age of the head of household, their level of education and their gender. With regard to family size, we expect that households with fewer members would consume more electricity per capita than larger families, considering the possible existence of scale economies. How age, education level and gender might affect electricity consumption is less obvious and is therefore an empirical question to be explored.

d. Living conditions

The remaining household level variables used in the model reflect living conditions, including the size of the household living area, the distance of the household to the nearest local commercial center and the frequency of electricity outages. Studies have shown that housing size is a key determinant of energy demand. For example, Liu and Yang (2003) found that in China's rural areas, as housing size declines, efficiency in resource use decreases and demand for resources increases. Accordingly, we expect that a household with a larger living space will need more electricity, and housing size will be positively related to electricity consumption. Households with unreliable electricity service would be more likely to make use of other fuels so that the frequency of outage is expected to be negatively correlated to electricity consumption. As far as distance of the household to the nearest local commercial center, how it affects electricity consumption is not obvious, although one might expect that homes in remote rural areas with unreliable electricity service would be more likely to make use of other fuels such as firewood or diesel for generators.

e. Local climate conditions

Part of the regional variation in electricity use by households can be explained by climatic differences owing to the need for space conditioning. Heating or cooling degree days would usually be considered a suitable indicator, but no appropriate data is available at the district level in China. Climatic conditions are largely determined by geographical location. The duration of sunlight in a day varies throughout the year, and basically depends upon latitude. In the same hemisphere, the higher the latitude, the shorter the day during winter. Thus, more artificial lighting might be needed at higher latitudes, which implies more electricity demand. Since climate conditions depend on geographical location, latitude at district level is used as the proxy variable for climate conditions.

f. Energy price

Energy prices will directly (or indirectly) affect electricity demand. Both electricity and gas prices are included in the model to capture the responsiveness of electricity demand to a change in price of itself and its substitutes. Since electricity pricing in China has been under tight government control, prices for residential electricity in each province have been largely fixed, uniform and adjusted only rarely (and with great controversy) until 2012 when the IBT scheme started nationwide (Liu, Margaritis, and Zhang, 2013). During the period this survey was conducted, the older fixed price scheme for electricity was still in effect.[a] As a result, there was limited intra-provincial variation in electricity price, which might produce collinearity in the data if region dummies are included in the model. Prices of residential gas, the main alternative energy fuel for household cooking, were also set by the government; hence the gas price variable may have similar collinearity problems. In order to avoid any collinearity arising from simultaneously using energy prices and region dummies in the model, region dummies are excluded from the independent variables.

- **Data**

The salient feature of residential electricity consumption cannot be determined without consideration of micro-level data. The advantage of survey data is that it better reflects the household characteristics and adds more details to our knowledge of residential consumption behavior. However, to date, empirical studies of residential electricity consumption in China using micro-level data are extremely rare. The dataset used here is built on a population sample of households representing the provinces of Beijing, Shanghai, and Guangdong, all of which are located along the eastern coast. The survey was conducted by Peking University and funding by the China Family Panel Studies (CFPS) project. The project aims to document social changes taking place in China by repeatedly collecting information from a sample of individuals, households, and communities over an extended period (Xie et al., 2014). The survey data contain socioeconomic characteristics on various aspects of the households. The first survey was carried out in 2008, covering 2375 households, of which 1,940 were followed up the next year.

The full sample of 1,940 households cannot be used because some households did not report electricity usage. Keeping the households that are observed in both years and with non-missing electricity usage for 2009, the sample size is reduced to 1,748 households. To avoid endogeneity of

[a] The nominal electricity price in 2009 for Beijing, Shanghai, and Guangdong was 0.488, 0.536, and 0.599 Yuan/ kWh, respectively.

explanatory variables that may give rise to estimation bias, notably those variables representing household wealth, we use observations lagged for one period (i.e., using 2008 data) to define income dummies and household assets. The dependent variable, electricity consumption, and other independent variables are based on observations from 2009.

One major limitation of this survey data is that it was not designed especially for studying energy use. Except for the quantity of electricity consumed, other detailed information on energy services are not available from this survey, such as amount of energy used for cooking and transportation, expenditures on specific fuels, and the quality of energy services. However, since this is one of very few comprehensive household surveys and covers both rural and urban areas of the three regions, together with other available information sources, it is still possible to estimate with some accuracy the levels of basic electricity needs in rural and urban households.

Descriptive statistics are reported in Table 3. In our sample of 1,748 households, monthly electricity consumption was 42.4 kWh per capita, which is much higher than the national average of 30.5kWh in 2009.[a] This is because the three regions where the data were collected are among the most developed regions of China.[b] For rural households in the sample, monthly electricity consumption per capita was 19.1 kWh, less than half of the 52.1 kWh in urban areas.

Table 3. Summary statistics of variables used in the study [a]

	Rural (514 observations)				urban (1234 observations)			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Family size (members)	4.0	1.7	1.0	11.0	3.2	1.4	1.0	15.0
Household living area (m2)	107.9	77.2	10.0	600.0	90.6	76.1	5.0	1103.0
Age of head of household (HH) (years)	53.0	11.4	15.0	94.0	53.5	13.6	0.0	95.0
Gender of HH (1=female, 0=male)	0.2	0.4	0.0	1.0	0.5	0.5	0.0	1.0
Education of HH (years)	6.8	2.6	3.0	15.0	9.0	3.4	1.0	18.0
Household distance to the nearest	24.6	21.3	0.0	300.0	17.4	16.3	0.0	240.0

[a] Based on annual consumption per capita of 365.9 kWh (Table 1).
[b] According to NBS (2011b), the average monthly electricity consumption across all three regions was 50 kWh per capita, so there may be a slight downward bias in the sample, which is likely the product of oversampling of rural population relative to its share in the overall population of the three regions (rural population in Beijing and Shanghai provinces are just over 10% and roughly one-third in Guangdong province (NBS 2013b).

commercial center (minutes) [b]								
Household has frequent electricity outages (1 = Yes, 0 = No)	0.03	0.18	0.00	1.00	0.01	0.11	0.00	1.00
Latitude of district	30.76	7.83	21.88	40.39	32.12	6.78	21.88	40.39
Household uses electricity for production (1 = Yes, 0 = No)	0.08	0.27	0	1	0.03	0.17	0	1
Household has stocks, bonds and deposits (10^4 yuan)	2.1	5.3	0.0	50.0	20	83	0	2000
Household has agricultural land (mu) [c]	8.2	36.3	0.0	800.0	0	0	0	0
Household has monthly electricity use (kWh per capita)	19.1	16.9	0.8	125.0	52	50	1	700
Household has disposable income annually (yuan)	7825	40708	20	90000	16785	33868	20	538000

[a] We use dummy variables to represent that the household has a female head, has frequent electricity outages, and uses electricity for productive activities. These dummies are equal to 1 for the households who have the corresponding backgrounds and 0 otherwise.
[b] This indicator means the travel time by whatever mode is used most commonly by the individual household.
[c] The "mu" is a Chinese unit of area, 1 hectare = 15 mu.

- **Estimation results**

Of the 1,783 households in the sample, several households did not report their income or other key explanatory variables, such as living area and the distance to the commercial center. Though using only complete observations certainly simplifies analysis, it leads to information loss in the incomplete observations. For the explanatory variables with missing values, we adopt Rubin's (1987) multiple-imputation (MI) technique to fill in those missing values, specifically, the predictive mean matching imputation method. Instead of filling in a single value for each missing value, the MI procedure replaces each missing value with a set of plausible values that represent the uncertainty about the right value to impute. Hereafter, we use the multiply imputed data to do analysis by using standard estimation procedure for complete data and combining the results from these analyses. No matter which complete-data analysis is used, the process of combining results from different data sets is essentially the same (Rubin, 1987). A complete list of explanatory variables can be found in Table 4, along with the parameter estimates and their associated *t* statistics.

- **Effects of the control variables on electricity**

Table 4 presents the series of income dummy decile variables (the reference is decile 1, the poorest 10% of households), and the dummy variable is equal to 1 for households categorized as group *i* (*i*=1,2, 3,…, 10), and 0 otherwise.

Table 4. GLM estimates of household's electricity demand [a]

	Rural [d]		Urban	
Variable	Coef.	t-statistic [c]	Coef.	t-statistic
Constant	5.1720***	2.88	5.1452 ***	6.63
Number of family members	-0.1427***	-6.87	-0.1778 ***	-11.95
Log of household living area	0.1464***	2.67	0.1788 ***	6.08
Age of head of household	-0.0053*	-1.85	-0.0001	-0.60
Gender of head of household	0.0630	0.83	0.1546 ***	3.77
Education of head of household (years)	0.0133	1.00	0.0345 ***	5.35
Distance to local commercial center	-0.0042***	-2.68	0.0000	-0.01
Household has frequent electricity outages (1 = Yes,0 = No)	-0.1554	-0.92	-0.0648	-0.37
Latitude of district	-0.0825**	-2.40	-0.0848 ***	-5.41
Area of agricultural land of household	0.0003	0.42		
Stocks, bonds and deposits of household			0.0000	-0.08
Household uses electricity for production (1 = Yes, 0 = No)	0.4845***	4.37	0.3240 ***	2.74
Log price of electricity	-3.5902***	-4.10	-2.9125 ***	-7.48
Log price of gas	-2.0307**	-2.19	-1.3587 ***	-3.20
Household income by decile [b]				
2	-0.0283	-0.20	0.0075	0.07
3	-0.0497	-0.37	0.0394	0.39
4	-0.0135	-0.10	0.1448	1.37
5	-0.0572	-0.45	0.3324 ***	3.41
6	0.1410	1.04	0.2529 **	2.55
7	0.3353 **	2.48	0.3812 ***	3.79
8	0.2716 **	2.02	0.4063 ***	4.20
9	0.2896 **	1.98	0.3930 ***	4.00
10	0.3890 **	2.88	0.4625 ***	4.47
	F =20.29 Prob > F = 0.0000		F = 19.35 [d] Prob > F = 0.0000	

Note: *, ** and *** reflect significance level of 0.10, 0.05 and 0.01, respectively.
[a] The model is estimated with maximum likelihood optimization, and the results are multiple-imputation estimates,where the number of imputations =30.
[b] Dummy variables categorize per capita income of households by income decile, and the excluded category in the dummies is decile 1.
[c] Figures in column (3) and column (5) are t-statistics of the estimated coefficients.

- **Family size and housing size**

Family size and household living area significantly influence household electricity demand in both rural and urban areas. We find that family size has a significant negative impact on per capita electricity consumption, which is consistent with other studies, such as Zhou and Teng (2013) and Shi et al. (2012). Increasing rural family size by 1% increases household demand per capita for electricity, ceteris paribus, by 0.143%, while for urban families the resulting increase is 0.178%. Holding aggregate household electricity use constant, on one hand, households with more members can afford electricity; on the other hand, economy of scale in electricity use could result in larger families consuming less electricity per capita. As expected, larger living area increases household electricity consumption. A 1% increase in housing size results in a 0.146% increase in the demand for electricity by rural households, and a 0.179% increase by urban households.

- **Demographic factors**

As far as demographic characteristics are concerned, of the three variables representing age, education level and gender of the household head, a significant relationship was only found between the age of the head of household and electricity demand in rural areas, at a 10% level of significance. By contrast, gender and education were found to have significant influence on electricity demand in urban areas.

In rural areas, an increase of age of the head of household by one year results in a 0.005% decrease in electricity consumption, which implies that older people tend to be more energy-saving.

In urban areas, an increase of the education level of the head of household by one year results in a 0.035% increase in electricity consumption. This is partly because the education level of the head of household may affect the fuel choice of a family, and the choice is usually biased towards electricity. Démurger and Fournier (2011) pointed out that increasing education is a key factor in energy consumption behavior, especially when dealing with energy source switching behavior. Several studies on energy transitions have found that a higher level of education is associated with households choosing to use more modern and efficient sources of energy (Luo and Zhang, 2008; Pachauri and Jiang, 2008). In the sample, the average education level for heads of household in rural and urban areas is 6.8 and 9.0 years respectively. 47.3% of the rural household heads had a primary school education or lower, and only 0.8% had an undergraduate education or higher. By contrast, the proportion of urban heads of household with no more than a primary school education was 21.2%, whereas those with an undergraduate education or higher was 15.1%. The low level of education overall helps explain the insignificance of its impact on consumption behavior of rural households.

It is striking that urban households with a female head of household actually consume more electricity, as it is a common view that women are more frugal. For example, a study of the transport sector in industrialized countries found that women in all age and income groups consumed less energy (United Nations, 2005). Similarly, Barnes et al. (2011) found that a male-headed household would tend to consume more energy and Khandker et al. (2010) also found that male-headed households tend to consume more electricity. By contrast, all else being equal, we found that a female-headed household in our sample has a small but statistically significant 0.155% increase in its electricity consumption. In a female-headed household, women may have more say over the fuels they use (e.g., they may prefer electricity over traditional fuels such as firewood, dung and agricultural wastes) and have more say over appliance purchases and utilization.

- **Distance to commercial center**

By examining the distance from a household to its closest commercial center, the impact of transportation convenience can be tested. It is not surprising to find that distance affects the electricity needs of rural households rather than urban households. In urban areas, where a family lives may influence travel patterns and thereby affect the demand for gasoline, but it does not affect the demand for electricity. For a rural family, a longer distance to the local commercial center is related to lower electricity consumption. Greater distance to the commercial center implies easy access to the mountains and forests where rural households can collect firewood for cooking, thereby reducing the demand for electricity.

- **Latitude of district**

The estimates of latitude are -0.083 and -0.085 respectively for rural and urban families, both of which are significant. We find that households at higher latitude consume less electricity. At higher latitudes, due to shorter days during winter and average lower temperatures, energy needs increase for heating, hot water and lighting whereas needs for cooling decrease. Therefore, the net impact of variations in latitude on electricity consumption depends on which of these two opposite effects dominates: increased demand for heating and lighting or decreased demand for cooling. Of the three regions, Beijing is located at the northernmost latitude with the longest winter and lowest annual mean temperature, while Guangdong is the southernmost location with the highest annual mean temperature. Shanghai and Guangzhou, both located south of the Yangtze River, experience long, hot summers and hence require more electricity for cooling, refrigeration and freezing purposes. Especially in Shanghai where it is cold and wet in the winter, electricity is extensively used for heating because there is no district heating network. Beijing experiences longer periods with colder temperatures and people have to heat their houses for up to half a year, hence requiring more energy for heating than other regions. However, higher heating demand does not necessarily translate into electricity demand, because household heating in winter is mainly provided by decentralized steam boilers or by large centralized boilers through a district heating network. According to official statistics (BBS, 2010), 75.3% of rural households and 94.4% of urban households in Beijing are covered by a district heating network. In addition, in the rural areas, using of stoves burning coal or wood still prevail. All of above factors lead to lower electricity demand for heating in Beijing, compared to the other two regions.

- **Energy prices**

The estimated coefficients of the two price variables indicate that rural residents are more sensitive to price changes than urban residents. The four coefficients of energy price are all negative and statistically significant. The elasticities of urban electricity consumption with respect to the two price variables are smaller than those their rural counterparts. Holding constant all other determinants of demand, a 1% increase in the price of electricity results in a 3.59% decrease in electricity demand by rural residents, and a 2.91% decrease by urban residents. The results provide evidence that raising prices of electricity may be more detrimental to rural families. A 1% increase in the price of natural gas results in a 1.36% decrease in the electricity demand by urban households, and a 2.03% decrease by rural households. Obviously, there is no substitution between the consumptions of coal and electricity, since the signs of the price estimates are the same.

- **Basic electricity needs**

The central hypothesis is that if there is a minimum amount of electricity consumption that a household needs for basic welfare, then electricity consumption up to that level would be unresponsive to changes in household income. Thus, the basic needs for electricity is determined by investigating the cut-off point after which electricity consumption start to be sensitive to income change. The estimated coefficients of income dummies are reported in the lower half part of Table 4. The main findings on the relationships between income and electricity demand are described as follows:

Firstly, electricity consumption at higher income deciles responds positively and significantly to changes in income, while electricity consumption at lower income deciles does not.

Secondly, at the same income decile, rural electricity demand is less sensitive to income than urban demand. For example, at the 8^{th} income decile, the elasticity of electricity demand with respect to income for urban households is 0.408 whereas for rural households it is only 0.272.

Thirdly, in both rural and urban areas, high-income families are more sensitive than low- income families to income changes. The energy "saturation" hypothesis states that the elasticity of energy demand with respect to income should decline as a country moves beyond a certain phase of development as supported by several empirical studies (Brookes, 1972; Galli, 1998; Medlock and Soligo, 2001). Accordingly, there might be a theoretical saturation point, after which household energy needs would not increase further proportionate with rising income. Apparently, for the case of China's electricity consumption, the saturation point is still far from having been reached.

On average, the cut-off point for rural and urban households appears at the 7th and 5th income deciles, respectively. Rural households have a lower cut-off income than urban households. More precisely, the household electricity demand in rural areas does not respond to income changes until after the 7th income decile and urban household demand for electricity does not respond to income changes until after the 5th income decile. For rural (urban) families, electricity consumption at the 7th (5th) income decile can be considered the threshold for basic needs or a measure of electricity poverty. Table 5 presents electricity consumption of rural and urban households by income decile. On average, the threshold for the basic needs level for electricity consumption is 22.8 kWh per capita per month in rural areas, and 47.7 kWh in urban areas, although there is still notable variation beyond the threshold.

Table 5. Electricity consumption by income decile

Income decile	Rural areas			Urban areas		
	Electricity per capita	Income per capita	Household population	Electricity per capita	Income per capita	Household population
1	10.6	366	4.0	38.3	624	3.0
2	11.4	1068	3.6	40.2	2562	3.1
3	10.1	2108	4.6	37.7	4430	3.4
4	12.7	2849	3.9	44.8	6103	3.3
5	12.8	3669	4.2	47.7	8228	3.1

6	15.9	4764	4.6	47.8	10994	3.0
7	22.8	6038	4.4	54.0	13729	2.9
8	20.3	7884	4.6	64.9	17273	2.8
9	24.3	10831	4.0	61.3	23262	2.9
10	27.1	34967	4.1	87.6	72943	2.4

It may seem surprising that electricity demand for a rural family is still much lower even when its per capita income is roughly equal to that of an urban family, but consider the differences in the energy mix between rural and urban households. Household energy consumption patterns changes dramatically from village to city. In urban areas, electricity is the main energy source for households. Using electricity for heating in winter and cooling in summer is far more common than in rural areas. Urban households have more appliances than rural households in terms of both quantity and variety, and electricity use for entertainment and household appliances is greater in urban areas. By contrast, in rural areas, many households still consume traditional biomass resources collected from forests and farmland for cooking, such as straw and fuel wood. Rural households mainly use electricity for lighting and some appliances like televisions, and the share of electricity used for lighting is larger in rural districts.

Energy transition theory suggests that there is a ladder of fuel preferences from low-quality biomass-based fuels to more efficient and versatile modern fuels (Leach, 1987; Leach, 1992; Masera et al, 2000). Theory predicts that energy forms used in rural households are less convenient and less efficient than those used in urban areas. Although detailed information about energy type consumed by the households is not available in this survey, the evidence supports the existence of fuel preferences, which can be observed by examining the fuels used for cooking in the sampled households (see Table 6). In our sample, 56.4% of rural households use firewood for cooking, 21% use gas, and 16.5% use electricity. By comparison, 83.3% of urban households use gas for cooking and 9.3% use electricity.

Table 6. Household Cooking Fuels (proportion of sampled households)

	Rural	Urban	Total
Firewood	56.4%	5.0%	19.5%
Electricity	16.5%	9.3%	11.4%
Gas	21.0%	83.1%	65.1%
Coal	3.0%	1.7%	2.6%
Solar	0.0%	0.2%	0.1%
Biogas	2.0%	0.2%	0.7%
Other	1.1%	0.4%	0.6%

Source: calculated by the authors, based on the sample used in this study.

Although coal use by households has declined in absolute terms, it remains an important source of heating energy in many provinces. In rural northern households, coal is still the main source of energy for winter space heating. Beijing is an extreme example – the average coal consumption of rural households in Beijing province is 567 kg, almost 16 times that of urban households in the province, which leads to its rural households having a higher primary energy consumption than urban households (BBS, 2010). Pachauri and Jiang (2008) also found that in China, primary energy consumption of rural households per capita exceeds that of urban households as a consequence of their continued dependence on inefficient solid fuels, even though urban households consume a larger share of electricity and fossil-based energy sources.

V. Conclusions

Any definition of basic energy needs is inevitably arbitrary in some sense, so no technique can unambiguously identify an “optimal” measure for basic electricity needs, which is an even more subjective concept. The method defining basic electricity needs used here at least does not specify any preset figure as the dividing line nor use an arbitrary share of income or expenditure to define it; rather, basic electricity needs is defined based on the concept of “energy poverty” and estimated from the electricity demand function. This method is based on actual household demand for electricity, after controlling for various exogenous factors that may influence the electricity demand of a household and therefore provides a region-specific measure. The empirical results of this study reveal that as follows:

Firstly, household electricity consumption becomes income-sensitive at higher income levels, controlling for characteristics of the household and district and other exogenous factors. Some household-related factors do significantly affect electricity consumption. For example, electricity consumption per capita tends to be higher if the household lives at lower latitudes, has a larger living area, has a smaller number of family members, or uses electricity as an input in its production.

Secondly, there exists a minimum level of electricity consumption that a household requires to satisfy some measure of basic needs and where electricity consumption up to that level is unresponsive to changes in household income. Until a household crosses the threshold, even if there is a decrease in household income, its electricity demand would not necessarily decrease, although its expenditure on electricity may increase significantly.

Finally, the basic electricity needs of rural households is less than that of urban households, and biomass and coal still play an important role in rural areas. In the case of China’s electricity consumption, the theoretical saturation point that household electricity needs would not rise further proportionately to income increase remains far from having been reached.

Though our study quantifies basic electricity needs for rural and urban households, setting any IBT block level will still subject to further discussion given its political sensitivity. There may be interest, for example, in differentiating our results by province since ultimately setting of blocks and tariffs is a provincial matter and there is a notable effect that latitude (heating and cooling degree days) has on the outcome.

The existence of an income threshold implies that the burden imposed by electricity expenditures could be high for low-income families if the electricity price rises. The concern is particularly salient in rural areas, as rural families are found to be more sensitive to changes in electricity price. Given the increasing price structure of the IBTs in China, it is critical to select the volume and price of the first block in an IBT scheme so as to mitigate the burden of expenditure on electricity for low-income families and thereby ensure access to basic energy services by explicitly targeting low-income families.

A major challenge in setting the level and rate of the first IBT block is that it too can become politicized. Boland and Whittington (1998) examine the history of IBT use in the water sector (over half of water utilities in Asia were using some form of IBT by the 1990s). They argue that the main difficulty is not a theoretical issue, but one of implementation, namely that “water utilities find it difficult to limit the size of the initial block for residential users due to political and other pressures”. As a result, the majority set the initial block at a level far higher than ‘basic needs’ (i.e., of 17 water utilities surveyed by the Asian Development Bank, only two set the first block at a level roughly that of the “basic needs” level of 4-5 cubic meters per month per household and the majority set the level at 15 cubic meters or higher).

Under the newly instituted IBT, Beijing households were able to keep the pre-existing rate for monthly usage of up to 240 kWh, pay roughly 10% more between 241-400 kWh, followed by a much more substantial increase in rates of 60% for consumption above 400 kWh (Lo, 2014). The schemes for other provinces are broadly similar with some relatively minor variation. Assuming an average of roughly 3 residents per urban household and 4 per rural household, we estimate basic needs to be only 90 kWh per month for rural households and roughly 150 kWh for urban households. Thus, the first IBT block appears to have been set at a level that is too high, roughly equivalent to the average consumption of the *top* decile of urban residents. The danger of such an approach is that, when introduced, only a very small percentage of residents will have needed to pay the highest rate and almost all residents would have fallen within the lowest block, which includes both those just barely able to meet their basic needs and those consuming at a significantly higher level. Therefore, the initial policy targets that motivated the introduction of the IBT, such as stimulating energy-saving behavior and subsidizing basic energy services for targeted consumers, will be difficult to achieve. The more positive interpretation though is that, from a political economy perspective, such a tariff would have been relatively easy to introduce given the situation in 2012, but, given the likelihood of continued increases in household residential consumption, over time fewer households will fall into the first block and more will be subject to the highest rate. Therefore such an approach may produce a more sustainable tariff structure that will become increasingly more effective over time.

There is, of course, much more work that must be done in this area. Our results are based on the results of a survey that was not intended primarily for studying energy consumption and so there would be significant benefit of being able to design and implement a survey with energy in mind.

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