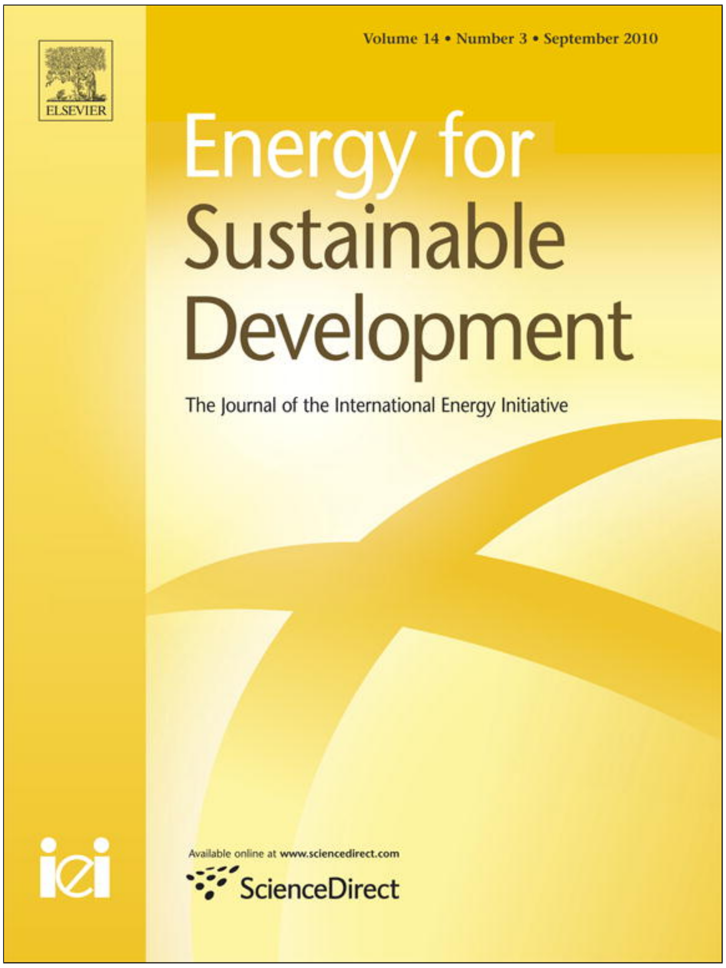
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Household level fuel switching in rural Hubei

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ABSTRACT

The majority of rural residents in China are dependent on traditional fuels, but the quality and quantity of existing data on the process of fuel switching in rural China are insufficient to have a clear picture of current conditions and a well-grounded outlook for the future. Based on an analysis of a rural household survey data in Hubei province in 2004, we explore patterns of residential fuel use within the conceptual framework of fuel switching using statistical approaches. Cross-sectional data show that the transition from biomass to modern commercial sources is still at an early stage, incomes may have to rise substantially in order for absolute biomass use to fall, and residential fuel use varies tremendously across geographic regions due to disparities in availability of different energy sources. Regression analysis using logit and tobit models suggest that income, fuel prices, demographic characteristics, and topography have significant effects on fuel switching. Moreover, while switching is occurring, the commercial energy source which appears to be the principal substitute for biomass in rural households is coal. Given that burning coal in the household is a major contributor to general air pollution in China and to negative health outcomes due to indoor air pollution, further transition to modern and clean fuels such as biogas, LPG, natural gas and electricity is important. Further income growth induced by New Countryside Construction and improvement of modern and clean energy accessibility will play a critical role in the switching process.

Introduction

China has the largest population in the world and more than half of its population lives in rural areas. The majority of rural residents are dependent on traditional fuels, which include various forms of biomass.[1] More than 250 million tons coal equivalent of biomass was burned for cooking fuel in 2002 (Tsinghua University, 2004). For many, this barely allows fulfillment of basic needs for cooking and space heating. Moreover, heavy reliance on biomass has raised pressing concerns over environmental consequences such as deforestation and soil erosion (Jiang and O'Neill, 2004). Speeding up the switch from biomass to modern energy is therefore of importance in China.

The quantity and quality of existing data on the process of fuel switching in rural China are insufficient to have a clear picture of current conditions and a well-ground outlook for the future. Existing analyses in China are largely based on aggregated statistics which are estimated on the basis of production (e.g. Tsinghua University, 2004; Jiang and O'Neill, 2004; Wang and Feng, 2001) or on surveys conducted in either one county or province in the eastern area (Wang and Feng, 1997; Wang et al., 1999, 2002) or in several counties across the country (China Academy of Forest Research, 2003).

In this paper we undertake an analysis of the survey of representative rural households in Hubei province of central China to describe patterns of rural energy use, the nature of the fuel-switching process and the determinants of fuel switching. The data is used to test two conceptual models of the fuel switching process (described in the following section). The focus in this paper is biomass because it is the main cooking fuel and information regarding its use is usually unavailable due to limited market transactions.

The following section provides a review of the literature regarding household energy choices and fuel switching, with a particular focus on cooking fuels. In the third section, we describe the survey implementation and some summary statistics. Following that we present a descriptive analysis focusing on patterns of energy use by income level and then, in the subsequent section, a regression analysis of the determinants of biomass energy use and the proportion derived from biomass. Finally, we summarize our conclusions.

Background

Studies in Mexico (Sheinbaum et al., 1996), China (Wang and Feng, 1997), South Africa (Davis, 1998), India (Reddy, 2003), and Guatemala (Heltberg, 2005) all find evidence of fuel switching in both urban and rural settings. However, there is no consensus on the

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[1] In this paper biomass refers to firewood and straw.

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Fig. 1. Map of the counties selected in Hubei province (left) and location of Hubei with China (right).

consequences of fuel switching for the absolute amount of different types of energy use. Regarding the consumption of biomass energy in particular, Leach (1992) argues that a basic feature of economic growth is the substitution of modern fuels for traditional biomass fuels, and hence a decline in absolute biomass use. However, while increasing evidence suggests that such a transition is rapidly occurring in urban areas of developing countries, the present situation and prospects for rural areas are much more uncertain. For example, Foley (1995) argues that substitution is not a major feature of fuel switching in rural households.

Until a decade ago, researchers had often attempted to explain the dynamics of energy use in families of varying incomes by reference to the "energy ladder" as a model for household decisions to substitute or to switch between available fuels (Leach, 1992). However, a growing body of empirical studies on household energy use reveals that multiple fuel use is common and that fuel switching does not occur as a series of simple, discrete steps. With increasing affluence, households adopt new fuels and technologies that serve as partial, rather than perfect, substitutes for more traditional ones (Masera et al., 2000). This "fuel stacking" model integrates four factors demonstrated to be essential in household decision making under conditions of resource scarcity or uncertainty: economics of fuels and stove types and access to fuels; technical characteristics of cook stoves and cooking practices; cultural preference; and health impacts.

Regarding the determinants of fuel switching, the literature has reached some consensus but important questions remain. Studies tend to agree that income is a key determinant of both the switch to new energy sources and total energy demand, although even here studies can be difficult to interpret and compare due to the use of different measures of income (Jiang and O'Neill, 2004). Due to the absence of income data, many studies linking household income to energy consumption use expenditure as a proxy for income (Elias and Victor, 2005). While income and expenditure indeed tend to move in the same direction, correlation between the two is far from perfect. For example, a survey of rural Chinese household by Jiang and O'Neill (2004) found the correlation coefficient (R2) between income and expenditure to be only 0.516. All studies find that household size is another key determinant of demand, with per capita energy use smaller in larger households due to economies of scale (Jiang and O'Neill, 2004). Changes in Mexican household size were even more important than income in determining per capita energy demand between 1970 and 1990 (Sheinbaum et al., 1996). Beyond these basic determinants, some researchers emphasize the importance of infrastructure for modern fuel distribution (Leach, 1992). However, a study in South Africa found that infrastructure has been of little importance (Davis, 1998).

Rural survey

Given that very little fuel data exists at the rural household level this survey was designed to collect up-to-date and accurate primary data on rural household fuel consumption in a particular region of China that had not been studied before. The goal was to evaluate current fuel consumption patterns and estimate the relationship between fuel switching and possible explanatory variables, such as income, fuel prices, family size, etc.

Study area

Hubei province is located in central China and covers about 180 thousand square kilometers (Fig. 1). There were about 60 million people in Hubei and the urbanization rate was one-third in 2004. Its economic development is very close to the national average and the net income of rural residents was about 2900 yuan[2] per capita in 2004 (Hubei Statistical Bureau, 2005).

There are 72 counties, of which 30 counties are in mountainous areas, 21 in hilly areas and 21 in the plains. Mountainous areas are the least developed and the plains much better developed. There is little coal resource in Hubei and most of the coal used in Hubei is imported from neighboring provinces. The diversity that exists within Hubei (particularly across its topographic zones) in level of economic development and resource access makes it a useful geographic region for analyzing the question of fuel switching as it provides variation on the key independent variables of interest.

Household sampling method

Counties were sampled using proportional stratified random sampling with a two-step process. The stratification factors were topography first and then level of economic development. The sample consisted of 20 counties: 6 in the plains (Caidian, Yincheng, Tianmen, Jiayu, Shishou, Xiaochang), 6 in the hilly region (Tuanfeng, Huangmei, Guangshui, Yidu, Laohekou, Zhongxiang) and 8 in the mountainous areas (Badong, Lichuan, Wufeng, Yunxian, Baokang, Yingshan, Nanzhang, Danjiangkou) (Fig. 1).

[2] Yuan is the unit of Chinese currency Renminbi; 1 US Dollar equals to about 8.1 yuan in 2004.

Once the counties were selected, households were sampled in a three-step process. The first and second steps were to select the township and village by random sampling. Two townships in each county were selected, and then two villages in each township were selected by random sampling. The last step was to systematically sample the households by selecting the first household at random and then continuing with households that were five houses apart (a total of five households in each village were sampled). The only departure from the random selection procedure was one household without electricity access. This selection method was used to ensure that households with different energy resource were included in the survey. In all, 401 farming household were selected in Hubei province.

Survey implementation

The Hubei rural household energy survey questionnaire contains a list of questions that the enumerators used to interview family heads or key family members. The questionnaire consisted of several parts. It measured socioeconomic and demographic status through questions on name, sex, age, occupation, net income and educational level of the responding family head. Also included were questions on family type, size, output of cereal and cash crop, worker wages and bonuses, etc. A section on household energy consumption included questions such as nature, quantity, and source of energy used by the responding household during a one year period. In addition, information was collected on price, transport distance, and labor utilized to obtain firewood. For household cooking, questions were asked on stove uses and the major kinds of energy used for cooking. Survey data was collected in Hubei Statistical Bureau, 2005 in collaboration with the Hubei Information Centre of the Hubei Statistical Bureau, which was involved in both the training and implementation. All the data collected are for 2004.

Summary statistics of households

The 20 counties chosen for the detailed household energy survey are at quite different levels of economic development. The counties can be considered as fully representative of Hubei province (Table 1) but cannot be considered as fully representative of China. However, they do cover a broad spectrum of economic and resource development. The 8 counties in mountainous regions, where travel is difficult, are among the lowest income levels. The average income per capita is about 2500 yuan. The 6 counties in the plains are much richer due to the rapidly growing rural industries (often located near the larger urban centers in these areas), and the average income per capita is more than 3200 yuan. The 6 counties in hilly areas provide an example of a moderate level of economic development and offer an opportunity to assess the effects of differences in income on rural fuel consumption.

Table 1
Basic economic indicators for rural households in Hubei.

Indicator	Average
Household size[a]	3.69
Net income (yuan/household/year)	11 551
Of which, worker wages and bonuses, etc	4789
Sale of grain, oil bean plants and livestock	3100
Sideline occupation	1669
Government subsidy or remittance from relatives	424
Other	1569
Expenditure (yuan/household/year)	9886
Of which, housing	2067
Education	2061
Food and clothing	1503
Medical care	1105
Living appliance	643
Traffic	322
Entertainment	84
Other	2101

Note: 1 US Dollar equals to about 8.1 yuan RMB in 2004, see footnote 2.
[a] There are two statistical approaches for rural residents in China. One is the Hukou system, based on official records. The other is based on surveying households to determine occupancy. In this paper, we use the latter. The difference between them is not trivial since so many rural laborers migrate to the urban areas for work without changes being recorded in the Hukou system.

Table 2
Household energy situation for consumption.

Energy type	Share of household using	Unit average price	Yearly amount used per household
Electricity	98.8%	0.511 yuan/kWh	417.34 kWh
LPG	39.8%	5.56 yuan/kg	14.81 kg
Biogas	5.5%	NA	NA
Coal	72.5%	0.43 yuan/kg	548.63 kg
Kerosene	11.0%	5.73 yuan/kg	0.35 kg
Diesel	2.7%	4.56 yuan/kg	0.66 kg
Petrol	19.2%	3.54 yuan/l	15.64 l
Firewood	76.5%	0.25 yuan/kg	1398.80 kg
Straw	65.3%	NA	815.63 kg
Charcoal	19.0%	2.04 yuan/kg	9.98 kg

Energy consumption pattern in rural hubei

For the household energy consumption situation, there are several major features to note. The first is that 99% of rural households have electricity access (Table 2), slightly higher than the national average level; the second is that coal is used extensively as cooking fuel in rural areas; finally, farmers are also using considerable amounts of liquefied petroleum gas (LPG) and other oil products (especially petrol for transport).

Fuel choice

Households, as to be expected, use a variety of energy sources to meet their needs. The percentages of households using various combinations of fuel and electricity have been calculated (Table 3). Households using a single type of fuel are rare. More than 99% of households use at least two types of fuel. The most common combination is electricity plus coal and biomass (15% of households). Households that use that combination plus at least one other fuel are another 46.4% (for a total of 61.4% of households). Those combinations of electricity, biomass and coal plus other fuels are: LPG (13.2%), charcoal (5.7%), kerosene, diesel or petrol (14.5%), or both LPG and charcoal (4.0%) and all other types (9.0%). Significantly, roughly one-third of households use both biomass and LPG (often considered with electricity as the cleanest and most modern of rural cooking fuels), with a number of those households also using coal. This is a clear indication that the fuel stacking model explains the rural household energy mix quite well. Out of the 401 households investigated, only 39 (9.7%) had abandoned the use of biomass.

Fuel consumption

Analysis of the 2004 rural Hubei household survey data shows that the average household total energy consumption was 426 kilogram standard coal equivalents (kgce).[3] Table 4 shows the decomposition of average total energy use by fuel type, indicating that biomass is still the main source, accounting for 65.1% of total energy use. Since the electricity is not just for cooking and heating, and petrol and diesel are almost always for transport, the share of biomass in cooking fuels is much higher. Significant amounts of coal are also consumed for cooking purposes. Consumption of coal is second only to firewood.

[3] The thermal content per kgce is about 7000 kilocalories.

Table 3
Percentage of households by type of fuel used.

Fuel type	%	Fuel type	%
Electricity only	0.2	Electricity + Kerosene + Diesel + Petrol + Coal + Biomass	14.5
Electricity + Coal	0.7	Electricity + LPG + Coal + Charcoal + Biomass	4.0
Electricity + LPG + Coal	2.2	Electricity + Coal + Charcoal + Biomass	5.7
Electricity + LPG + Coal + Charcoal	0.7	Electricity + LPG + Kerosene + Diesel + Petrol + Biomass	3.0
Electricity + LPG + Biogas + Kerosene + Diesel + Petrol + Coal	2.7	All types	9.0
Electricity + Biomass	8.0	Electricity + Kerosene + Diesel + Petrol + Biomass	7.0
Electricity + Coal + Biomass	15.0	Electricity + LPG + Biomass	4.0
Electricity + LPG + Coal + Biomass	13.2	Others	10.1
Total			100.0

Table 4
Rural household energy consumption by energy type in 2004 Energy consumption unit: kgce/head.

	Electricity	Kerosene, diesel and petrol	LPG	Biogas	Coal	Charcoal	Subtotal	Straw	Firewood	Subtotal	Total
Access rate (%)	98.8	38.2	39.8	5.5	72.5	19.0		65.3	76.5		
Consumption	40.5	5.8	6.1	NA	93.9	2.4	**148.7**	84.3	193.0	**277.3**	**426.0**
%	9.5	1.4	1.4		22.0	0.6	**34.9**	19.8	45.3	**65.1**	**100**

Note: I kgce = 7000 kilocalories = 2.5 kWh.

As noted above, nearly all of the households surveyed use electricity (396 out of 401 households), a significant difference between rural China and many other rural areas in the developing world where electricity access can be as low as 5% (as in Sub-Saharan Africa). Electricity consumption is related to the appliance stock in rural households (Table 5). As incomes increase and electricity service improves, households add more appliances, including additional lights, cooking appliance, televisions, fans, washing machine, water heater, and even air conditioner and refrigerator. Cooking with electricity is common in rural Hubei. However, access to electricity does not tell the whole story. It is necessary to make a distinction between accessibility and consumption, because many of the households with electric service can experience frequent power shutdowns.

Fuel consumption and income

The general picture of fuel consumption for rural households in Hubei is provided in Fig. 2. It suggests that commercial energy use (e.g. electricity, coal, LPG) increases with income but that the use of biomass declines only at higher income levels. This would also indicate that, on the aggregate, the fuel stacking model more accurately describes the pattern of energy consumption in rural Hubei.

According to the energy ladder and fuel stacking models, the different types of fuel consumption is correlated with income level. Plotting the fuel consumption as individual lines (Fig. 3) allows us to look at the individual energy trends more clearly. It shows that the consumption of firewood declined at relatively high income levels. On the other hand, the other major biomass source, straw, does not show a significant decrease in consumption with income but rather has the inverse relationship. This is because straw is mostly collected during harvesting, representing almost zero opportunity cost. At the same time, straw is mainly available on farms in the plains and the hills, areas that also have higher income levels. Firewood, however, is collected at the cost of additional labor. Firewood does exhibit the interesting property that middle income households appear to consume significant amounts. This fits with the idea that overall energy consumption initially rises as households gain more income but do not necessarily have access to more efficient energy sources or technologies. For commercial energy, the use of coal, especially for cooking, increased faster than electricity and LPG. This would indicate that firewood will mainly be substituted by coal. Compared to LPG and electricity, initial stove costs and the price of coal is much lower.

Besides income level, resource conditions and transport infrastructure are also relevant to energy consumption. The mountainous residents use more firewood and less straw than plain and hilly counterparts (Fig. 4). On average, the people in the plains use more coal and LPG than elsewhere. The situation appears to be one in which those in the plains have greater options for their energy needs. Their farms produce straw that is available at zero or very low cost, they are richer and can afford to purchase coal, and, if necessary, can also access firewood. Those in the hills also have the advantage of running

Table 5
Type and capacity of the electric equipment.

Type of electrical appliances	Share of household having	Average capacity per household with the appliance (watt)
Electric light	98.8%	212.25
Air conditioner	2.0%	1765.00
Electric fan	85.8%	95.73
Electric cooking appliance	62.5%	941.66
Water heater	10.0%	535.30
TV	95.0%	97.66
Video CD/DVD	40.3%	34.32
Washing machine	21.3%	420.61
Refrigerator	13.5%	145.56

Note: the power rating of different appliances was recorded during the survey visit.

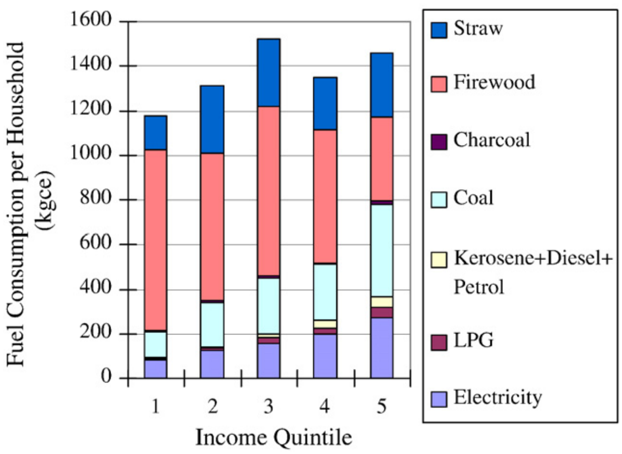

Fig. 2. Fuel consumption per household versus income quintiles.

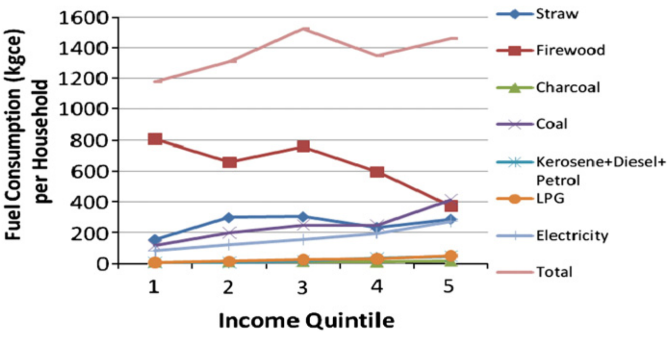

Fig. 3. Fuel consumption by income quintiles in rural Hubei household.

farms that produce straw and can also access firewood. However, either due to the fact that they cannot afford the coal or due to its unavailability in those areas, they do not consume as much coal as in the other regions. For those in the mountains, particularly at the lower income levels, options are much more limited. Firewood is the dominant source, but it comes with an opportunity cost. Straw is largely unavailable and coal is used by those that can afford it. Perhaps both income and topography are important, but without conducting the regression analysis it is difficult to know the importance of these two factors.

Therefore, judging by the statistics from the rural household survey in 2004, the fuel switching among rural households in present day Hubei is still at an early stage. With further socioeconomic development and increase in income, biomass will likely be substituted by commercial energy, but this process may be slow, especially for straw. Currently, the data suggest that income increases may have to be substantial (into the top deciles of current income) before the absolute amount of biomass use declines. This conclusion must be tentative, based as it is on cross-sectional analysis.

Determinants of energy demand

We further investigate the main driving forces of fuel switching in rural households. The energy ladder model proposes that as families gain socioeconomic status, they abandon technologies that are inefficient, less costly and more polluting, such as biomass. Fuel stacking happens when new fuels are added, but previous technologies and fuels are not completely abandoned. So, we can judge the two models by the share of households who abandoned biomass. Under conditions of resource scarcity or uncertainty, economics and access to fuels is an essential factor in household decision making. In China, coal is abundant, much cheaper than other commercial energy, and easily accessed, so it will probably become the main substitute of biomass. Income, household size, fuel prices, topography and other factors are hypothesized to be the main determinants of fuel switching.

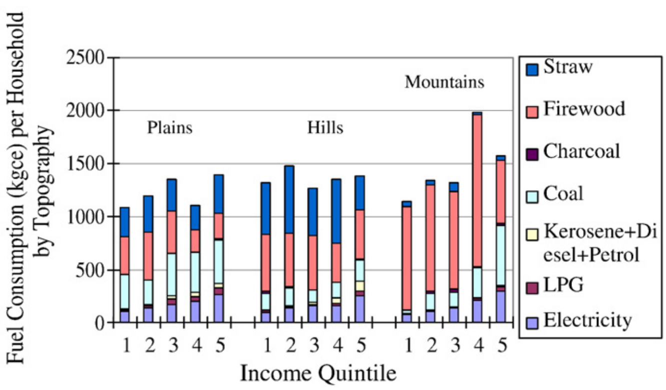

Fig. 4. Fuel consumption per household versus topography versus income quintile.

Here the focus is the use of biomass since it is the main fuel currently. We carry out a two-step regression analysis. Firstly, we model the use (versus non-use) of biomass using logit regression models. Next, we explore determinants of relative energy use by constructing tobit regression models that estimate the share of biomass in total fuel use. Because the use of electricity for cooking is difficult to separate from other uses of electricity, total energy consumption is used as a proxy variable for cooking fuel consumption since they move in the same direction. Furthermore, it is the share, not the total amount, of biomass that is chosen because the substitution of biomass is not always complete and new fuels are sometimes simply added into the consumption mix. Instead, its share declined when more new fuels are added.

Use (versus non-use) of biomass

To use or not use biomass is a binary choice. We can estimate it by using a logit model. Logit modeling is a regression technique used to explain the behavior of a dichotomous dependent variable. The logit model is

$$P(Y) = 1/\left(1 + e^{-Y}\right) \qquad (1)$$

where P is the probability that a household abandons the use of biomass, with Y = 1 if the household abandoned the use of biomass and 0 if it did not. The explanatory variables were income, household size, length of time since electricity access, topography, coal price and education. The price of coal in Hubei is determined by market forces, and the prices of LPG and electricity are administered and have no variation. So the coal price is selected as the substitute energy price and the electricity price is eliminated from the equation (Peng and Pan, 2008).

We assume that Y is linearly related to the variables shown below:

$$Y_i = \beta_0 + \delta_1 D_1 + \delta_2 D_2 + \delta_3 D_3 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \delta_4 D_4 + \mu \qquad (2)$$

where $Y_i = 1$ if non-use of biomass, 0 otherwise; β_0 is constant; D_1, D_2, D_3 refer to topography and is plain, hilly or mountainous areas respectively[4]; X_1 is the net income per capita per year; X_2 refers the household size; X_3 is the length of time since the household received access to electricity and represents the level of infrastructure development; X_4 refers to coal price. D_4, the education level of household head, is a dummy variable and equals to 1 if high school and above, otherwise 0; μ is disturbance. In a logit model all the regressors are involved in computing the changes in probability, and the rate of change in the probability is given by $\beta_j P_i(1 - P_i)$, where β_j is the coefficient of the jth regressors.

The data base that we use includes information for 401 households, of which 39 households did not use biomass. Table 6 provides a brief description of all of the variables used for estimation.

The coefficients are estimated by maximizing the likelihood function and the empirical results are given in Table 7.

All of the independent variables except the education level have the expected signs and are significant. The coefficient values can be used to interpret the effect of independent variables on probability of dependent variable. With the increase of income, households tend to abandon the use of biomass. Household size and time length of

[4] Regressions containing dummy variables are easily estimated by "dropping out" one of the categories but the result is awkward to interpret. The equation can be transformed into a more easily interpretable form by adding on an appropriately chosen constant to coefficient. For more details, see Suits (1984).

Table 6
Sample statistics for logit regression.

Variable	Description	Observations
Y	Use biomass or not by household, dummy, D = 1,not use; D = 0, use	D = 1, 39 observations; D = 0, 362 observations
D_1	Plain, dummy	D_1 = 1, 120 observations
D_2	Hilly, dummy	D_2 = 1, 120 observations
D_3	Mountainous, dummy	D_3 = 1, 161 observations
X_1	Net income per capita (1000 yuan/capita)	401
X_2	Household size	401
X_3	Time since electricity access (years)	401
X_4	Coal price (yuan/kgce)	401
D_4	Education level of household head, dummy, D4 = 1 if high school and above; D4 = 0 otherwise	D_4 = 1, 56 observations

electricity access also have positive effect due to scale economy and infrastructural construction. The price increase of coal has negative effect on the probability of household to abandon the use of biomass. The residents in plain areas tend not to use biomass because there is much less biomass resource than hilly and mountainous area. The residents in hilly areas tend not to abandon the use of biomass because they are positioned to have access to both forest sources and agricultural residues, making biomass more accessible than either the mountains or the plains. When the residents' education level is higher, they tend not to abandon the use of biomass. So schooling is not a sufficient force to realize the complete energy transition.

Share of biomass in total energy

The fuel switch can be defined as a decrease in the proportion of household energy derived from biomass, although the biomass substitution is not a major feature of the fuel switching in rural households. Because 39 out of 401 households abandoned the use of biomass, it is a left censored dataset. For this censored data, we use the tobit model and its specification is

$$Y^* = \beta_0 + \delta_1 D_1 + \delta_2 D_2 + \delta_3 D_3 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \delta_4 D_4 + \mu \text{ where } \mu|x \sim N\left(0, \acute{o}^2\right)$$

$$Y = \max(0, Y^*) \text{ where } Y^* \text{ is not observed} \tag{3}$$

Table 7
Logit regression analysis of the use versus non-use of biomass by rural households.

Independent variable	Coefficient
Intercept	−3.1334**
Plain (D_1)	0.1280**
Hilly (D_2)	−2.2551***
Mountainous (D_3)	−1.0068***
Net income per capita (X_1)	0.3520***
Household size (X_2)	0.3552***
Time since electricity access (X_3)	0.0547**
Coal price (X_4)	−4.0917***
Education level (D_4)	−0.1208
Akaike Information Criterion: 0.5359	

Note: (1) Akaike Information Criterion (AIC) is used in model selection for non-nested alternatives and smaller values of the AIC are preferred.
(2) Quasi-maximum Likelihood (QML) (Huber/White) standard errors and covariance estimator, which are robust in the sense that they produce consistent estimates of the parameters of a correctly specified conditional mean, even if the distribution is incorrectly specified.
(3) *significant at 10%, ** 5%, ***1% level.

Table 8
Estimation output of household biomass share in total energy. Dependent variable: share of biomass in total energy. Method: ML-censored normal (TOBIT).

Independent variable	Coefficient	Slope
Constant	0.6886***	0.6216***
Plain (D_1)	−0.1799***	−0.1624***
Hill (D_2)	0.0444	0.0401
Mountain (D_3)	0.0452	0.0408
Net income per capita (X_1)	−0.0586***	−0.0529***
Household size (X_2)	−0.0500***	−0.0451***
Time since electricity access (X_3)	−0.0012	−0.0011
Coal price (X_4)	0.5269***	0.4757***
Education level (D_4)	−0.0845**	−0.0763**
AIC: 0.477		

Note: * is significant at 10% level, and ** at 5%, and *** at 1%.

where Y is the share of biomass. The definition and sample statistics of explanatory variables are the same as model (2) and Table 6.

The method of maximum likelihood is used to estimate the parameters of model (3) and the results are given in Table 8. The slope is calculated by '$\beta \times P(Y > 0)$'.

All of the variables have the expected signs. Increasing levels of income tends to result in a decrease in the share of biomass in total energy consumption. Household size is negatively related to biomass share due to economies of scale. When the residents' education level is higher, they use less biomass or more commercial fuel (possibly because their opportunity cost of biomass collection is increasing). Coal is the competing fuel with biomass, so increasing coal price leads to more consumption of biomass. The amount of time since the household received electricity access has the expected sign but is not significant. As expected, the residents in the plains area tend to use less biomass.

Conclusions

Cross-sectional data from rural Hubei households show that the transition from biomass to modern commercial sources is still at an early stage, given that biomass still accounts for about two-thirds of the total energy used by rural households. The pattern of household consumption is useful for distinguishing between different conceptual models of the energy transition process. The data presented here confirm other findings that the fuel stacking model is a more accurate description of household energy than the energy ladder model. Despite the use of other cooking fuels in rural Hubei, less than 10% of households abandoned the use of biomass and biomass use falls in absolute terms only at much higher levels of household income. This suggests that decline in biomass use may be slow, and incomes may have to rise substantially in order for absolute biomass use to fall. The Chinese government is undertaking a number of measures to both improve rural livelihoods and to expand access and availability of modern and clean energy services. For example, the New Countryside Construction program has a number of elements (such as phasing out taxes on agricultural products) to increase the net income of farmers and the National Development and Reform Commission has funded projects for improving rural electricity grids and expanding rural access. Such measures, if they can raise incomes and ensure greater availability to a variety of energy sources will play a crucial role in the switching process. Moreover, while the switch away from biomass is occurring, the commercial energy source which appears to be the principal substitute for biomass in rural households is coal. Given that burning coal in the household is a major contributor of air pollution in China, further switching to modern and clean fuels such as biogas, LPG, natural gas and electricity is important.

Finally, the regression analysis suggests that, in addition to income, fuel prices, household size, infrastructure, and topography have significant effects on fuel switching; education can also play a role in the share of biomass. Thus, as changes occur in education level of rural residents, additional shifts in fuel use should be expected.

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Appendix A

Table 9
Index of standard coal efficiency conversion of all types of energy.
Source: Statistics Reporting System on Energy, 1986, China State Statistical Bureau.

Energy Type	Electricity	Oil	LPG	Biogas	Coal	Charcoal	Straw	Firewood
Unit	kWh	kg	M^3	M^3	kg	kg	kg	kg
Standard coal efficiency (kgce/unit)	0.404	1.46	1.71	0.71	0.71	1.00	0.43	0.57

Note: The thermal content per kgce is about 7000 kilocalories, see footnote 3.

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