# Poverty and firewood consumption: A case study of rural households in northern China

Sylvie Démurger, Martin Fournier

GROUPE D'ANALYSE ET DE THÉORIE ÉCONOMIQUE LYON - ST ÉTIENNE

W P 1020

# Poverty and firewood consumption: A case study of rural households in northern China

Sylvie Démurger, Martin Fournier

Septembre 2010

Documents de travail | Working Papers

**GATE Groupe d'Analyse et de Théorie Économique Lyon-St Étienne**

93, chemin des Mouilles  69130 Ecully – France
Tel. +33 (0)4 72 86 60 60
Fax +33 (0)4 72 86 60 90

6, rue Basse des Rives 42023 Saint-Etienne cedex 02 – France
Tel.  +33 (0)4 77 42 19 60
Fax. +33 (0)4 77 42 19 50

Messagerie électronique / Email :  gate@gate.cnrs.fr
Téléchargement / Download : http://www.gate.cnrs.fr  – Publications / Working Papers

# Poverty and firewood consumption:

# A case study of rural households in northern China*

**Sylvie Démurger**

Université de Lyon, Université Lyon 2, F-69007, Lyon, France

CNRS, GATE Lyon-St Etienne, UMR 5824,
93 Chemin des Mouilles, Ecully, F-69130, France

CEFC, CNRS, USR 3331,
Wanchai Central Building, 89 Lockhart Road, Wanchai, Hong Kong

E-mail: *demurger@gate.cnrs.fr*

**Martin Fournier**

Université de Lyon, Université Lyon 2, F-69007, Lyon, France

CNRS, GATE Lyon-St Etienne, UMR 5824,
93 Chemin des Mouilles, Ecully, F-69130, France

E-mail: *fournier@gate.cnrs.fr*

***Corresponding author**:* Sylvie Démurger - Tel: +33(0) 472 86 61 05 - Fax: +33(0) 472 86 60 90

* This paper is drawn from a research project funded by the French National Centre for Scientific Research (CNRS). The authors wish to thank Junqing Li, Pascal Marty and Weiyong Yang as well as students from the Beijing University of Forestry for precious collaboration in carrying out the household survey. We are also grateful to Jean-Marie Baland, Pierre Dubois, Nico Heerink, Mbolatiana Rambonilaza and two anonymous referees for useful comments on earlier versions of the paper.

# Poverty and firewood consumption:

# A case study of rural households in northern China

**Abstract**:
This paper discusses the determinants of firewood consumption in a poor township in rural northern China, with a special focus on the relationship between households' economic wealth and firewood consumption. We find strong support for the poverty-environment hypothesis since household economic wealth is a significant and negative determinant of firewood consumption. Firewood can therefore be considered as an inferior good for the whole population in the rural area under study, although further evidence shows that at the top of the wealth distribution, there might be a floor effect in the decreasing firewood consumption. Besides economic wealth, our analysis also shows that the own-price effect is important in explaining firewood consumption behavior, the price effect gaining importance with rising incomes. Finally, increasing education is also found to be a key factor in energy consumption behavior, especially when dealing with energy source switching behavior.

**Key words**: firewood consumption, poverty, natural resources protection, China.

**JEL codes**: Q23, Q28, I31, O12, C3.

# Poverty and firewood consumption:

# A case study of rural households in northern China

## 1. Introduction

In China as in most developing countries, wood is a key source of energy for rural residents. Despite the extremely rapid economic growth that China has experienced over the last 30 years, a large number of rural households still heavily depend on traditional biomass energy for both heating and cooking, especially in remote areas where it is sometimes the only energy available. Hence, firewood and straw remain major sources of total rural energy consumption although their share has decreased over time. According to Jiang and O'Neill (2004), biomass was still used by about two-thirds of rural households and accounted for 60 to 71% of total energy use in rural China at the end of the 1990s[1]. In northern China, Zhou *et al.* (2008) report a proportion of traditional biomass energy consumption to total energy consumption of 47.2% in 2005 (down from 56% in 1996).

The still important use of biomass fuel in rural China results from a rather slow energy transition process during the reform period. Overall trends show that per capita rural household energy consumption increased at an annual growth rate of about 1.8% between 1980 and 2005, from 329 to 514 kg of standard coal equivalent (kgce) (Wang & Feng, 2001; Zhou *et al.*, 2008). This general increase has been driven by a continuing increase in commercial energy use, while the use of biomass energy started to fall in absolute terms in the 1990s. In particular, firewood consumption first increased in the 1980s before decreasing in the following decade, whereas the use of agricultural residues remained roughly constant over the whole period (Jiang & O'Neill, 2004). Increasing rural income as well as a better accessibility to modern commercial fuels, mostly coal and electricity that

[1] Data on biomass energy use in rural China are scarce. Aggregate statistics based on estimates provided by the Ministry of Agriculture report an overall decrease in the share of biomass energy from 84% in 1980 to 60% in 1996. National rural household survey data from the State Statistical Bureau in 1999 indicate a higher biomass proportion of 71% (Jiang & O'Neill, 2004).

respectively accounted for 24% and 5% of rural household energy use in 1995 (Wang & Feng, 2001), contributed to the energy transition in rural China during the 1990s.

Heavy reliance on biomass fuels in developing countries has raised global concerns over both environmental consequences such as forest degradation and soil erosion, and the adverse health consequences of indoor air pollution generated by burning wood, animal dung or agricultural residues (Bruce *et al.*, 2000). The impact of firewood collection on forest degradation and on its relationship with rural livelihood has been largely debated, the issue receiving varying attention over time (Arnold *et al.*, 2003; 2006). In the 1970s and early 1980s, some studies argued that increasing firewood consumption was threatening the sustainable development of forest resources (Anderson & Fishwick, 1984; Eckholm, 1975). The reappraisal of the magnitude of the phenomenon in the late 1980s led to a lower emphasis on the issue (Dewees, 1989; Leach & Mearns, 1988), although it is widely acknowledged that local communities may threaten natural environment and forest regeneration by taking a lot out of non-agricultural areas.

In the evaluation of the environmental impact of firewood collection, forest degradation rather than deforestation is emphasized because the former is deeply linked to the behavior of local population, including firewood collection, over-grazing, fires, whereas the latter is mostly due to forest exploitation and commercial logging (Duraiappah, 1998; Trossero, 2002; Wunder, 2001). In the broader debate about poverty and the environment, forest degradation is also seen as a source of further impoverishment for poor people who strongly depend upon forest resources and as such, are particularly vulnerable to environmental degradation (Cavendish, 2000; Duraiappah, 1996; 1998). When firewood becomes scarce and more difficult to access, the increase in firewood collection time, the resort to lower substitutes usually used as animal fodder (e.g. crop residues) or soil fertilizer (e.g. animal dung), and additional indirect financial costs related to the increase in firewood price or a substitution towards more expensive sources of energy, all contribute to a decreasing well-being for local people.

Environmental protection has reached the top priorities of the Chinese government agenda in the 2000s, with the general objective of achieving a “sustainable development” path. Strategies to address these issues include the creation of a number of nature reserves as well as more focused policies such as the Natural Forest Protection Program and the Sloping Land Conversion Program implemented from the end of the 1990s[2]. As discussed by Shyamsundar and Kramer (1996), conservation efforts that exclude people very often conflict with local subsistence needs in developing countries, and this may considerably weaken the successful enforcement of forest protection measures. In order to target appropriate policies towards improved ecological conditions and better standard of living for local people, it is thus important to understand rural households' dependence on forests and the ease with which they can switch to alternative fuels. In a recent and well-documented review, Cooke *et al.* (2008) underline three key demand-side policies to alleviate problems related to firewood scarcity and dependency, and to make dependent people less vulnerable. These demand-side options consist of "promoting the use of alternative modern fuels, promoting more-efficient use of fuelwood and promoting income growth" (p. 116). In a similar vein, the general objective of this paper is to evaluate how such demand-side policies can be expected to reduce household dependence upon firewood in rural China. More specifically, we will focus on understanding firewood consumption behavior and its particular link with poverty by providing household-based evidence on the determinants of such behavior.

In this perspective, various inter-related questions can be raised. First, does biomass consumption reduce when income grows? If the relationship is found to be negative, the pressure on forests can be expected to decrease as a country develops. The empirical literature on the *poverty-environmental hypothesis* (PEH) addresses this question and states that poor households rely more on environmental resources than the non-poor. Where evidence of the PEH can be found, there are at least two main policy implications. First, poverty alleviation is a precondition for environment sustainability. Second, environmental protection policies based on a drastic limitation of access to common resources increase rural inequality and deepen poverty because poorer households suffer more intensively from the deprivation of the resource. Moreover, a potentially important side-effect is that increased inequality and poverty may in turn hamper environmental protection by weakening social cohesion that is needed for enforcing a sound environmental management (World Bank, 2003).

[2] For a review on the shift of the Chinese forest policy from a timber production strategy to a strategy of resource and ecosystem conservation and restoration, see e.g. Démurger *et al.* (2009).

A complementary question relates to the substitution patterns: what are the determinants of modern fuel use? This question falls within the scope of the "energy ladder" hypothesis, which states that households switch their fuel use from biomass to modern energy sources as a country develops and income increases, implying that firewood is an inferior good (Arnold *et al.*, 2006). Here again, an increase in income helps households to shift from traditional biomass to modern fuels. Additionally, infrastructure and market access as well as the price of modern fuels and the cost of end use technologies are important factors for adopting modern fuels (Adeoti *et al.*, 2001; Reddy, 2003).

Although forest degradation is an extremely topical issue in China, the growing empirical literature on firewood consumption and forest degradation mostly focuses on India, Nepal, or African countries (Adhikari *et al.*, 2004; Amacher *et al.*, 1993; 1996; 1999; Baland *et al.*, 2010; Heltberg *et al.*, 2000; Mekkonen, 1999), and surprisingly, to our knowledge, only two papers deal with the issue in southern China (Chen *et al.*, 2006; Shi *et al.*, 2009). This paper intends to contribute to fill the gap by investigating the determinants of firewood consumption in a geographically different context. We use an original household survey conducted in December 2001 in a rural township in northernmost Beijing municipality. Biomass use varies quite significantly across China depending on various factors such as the availability of other energy sources, as well as the geographical and topological characteristics of the area (Jiang & O'Neill, 2004; Zhou *et al.*, 2008). With longer and colder winters, the northern region is characterized by a per capita rural energy consumption level that is 33% higher than in the southern region (Zhou *et al.*, 2008). In northern China, the ecological environment is also more vulnerable, as illustrated by serious soil erosion or water shortage. The studied township, where a municipal-level nature reserve was created in late 1999, is illustrative of this vulnerability. It is located upstream of the Miyun reservoir, which is Beijing municipality's most important source of drinking water, and one of the objectives of the nature reserve is to strengthen the "green shelter" between Beijing city and northern arid areas. Through the case study of this township, this paper also aims at assessing to what extent forest protection policies may affect economic welfare in rural China.

The paper is organized as follows. Using descriptive statistics from the household survey, section 2 analyzes the general dependence of households upon forest resources as well as energy consumption patterns in the studied villages. Section 3 discusses the theoretical linkages between wealth and consumption choice in terms of firewood and firewood substitutes. Section 4 evaluates the respective magnitude of income and own-price effects in households' decision for firewood consumption through the econometric estimation of firewood consumption equations as well as the estimation of a choice model for the use of alternative energy sources. Section 5 summarizes the findings and discusses policy implications.

## 2. Labagoumen township study area and data

### *2.1. Forest policies in Labagoumen township*

Labagoumen township is the northernmost group of villages in Beijing municipality on the Hebei border[3], with a population of about 7000 inhabitants. The township is surrounded by high and steep forested mountains. Areas above 800m account for 44% of total land and the altitude varies from 424m to 1705m. Forest land represents 83% of total land whereas arable land only accounts for 3%. The township remoteness and harsh continental climate make households' energy needs for heating substantial during winter. The annual temperatures average 7°C to 9°C, with temperatures ranging from -12°C to -8°C during the coldest month (January).

Like most of the forested areas in China, Labagoumen township has gone through very different waves in terms of forest depletion or protection. Interviews conducted with several village heads in the township all indicate that during the 1960s and the 1970s, there were basically no restrictions and no rules regarding timber logging. In the 1980s, a first step in forest protection was made with the imposition of quotas and logging planning. Further restrictions have been progressively enforced during the 1990s, up to the implementation of the Natural Forest Protection Program in 1998 and the ban on access to mountains to favor the natural regeneration of the forest.

Apart from the implementation of national policies, a nature reserve has been formally set up in December 1999, under the responsibility of Beijing municipality, to protect natural secondary forest. In the township, the most important sources of forest degradation are firewood collection and cattle grazing, and as a consequence, the major environmental issue is to restrict local population access to forest. More precisely, the objectives of the nature reserve are *i)* the protection of the largest natural forest in the Beijing area, *ii)* biodiversity conservation, *iii)* the strengthening of the "green shelter" between Beijing city and northern arid areas, and *iv)* the protection of tourist resources in Beijing municipality. The nature reserve has been divided into three zones: a core area where all human activities are forbidden, a buffer area where building is forbidden but some economic activities are tolerated (including non-wood products gathering and tree planting), and an experimental area where the local population is allowed to live and engage in agricultural activities.

Given the various national and locally-designed policies, households were officially facing the following restrictions at the time of the field survey in December 2001: *i)* a logging ban on timber, *ii)* a pasture ban imposing cattle to remain in villages, and *iii)* a restricted access to the core and buffer areas of the nature reserve. However, in practice, some restrictions were not fully enforced. Indeed, most villagers were not clearly aware of the restrictions imposed by the nature reserve. They were still collecting firewood as well as non-wood products in all areas of the nature reserve and cattle were grazing around forest areas. The most sizable effect on rural population was the local sawmills closure imposed by the national logging ban on natural forests. In this context, we can consider the situation in 2001 as an *ex-ante* observation prior to the full enforcement of the nature reserve restrictions. In the following, we will thus address the question of the potential impact of these restrictions on local population livelihood.

### *2.2. Survey data*

Data for the study come from a household survey carried out in 10 villages in Labagoumen township in December 2001. The survey was designed to assess the potential impact of biodiversity conservation on local population through the analysis of specific socio-economic behavior. Research villages in the township were purposively selected to reflect the spectrum across various dimensions, including local economic opportunities, market access, forest access and proximity to the nature

---

[3] Beijing municipality is one of the 4 big metropolitan areas directly under the central government level in China. Its administrative structure comprises the following units: Beijing city, 4 urban districts, 6 sub-urban districts and

reserve. Within each village, about 30 households were randomly selected, and interviewed about their production and consumption activities for the whole year 2001 on a face-to-face basis by enumerators from Beijing Forestry University. The survey questionnaire includes detailed information on household and individual characteristics, energy consumption, and firewood collection.

Tables 1 and 2 provide descriptive statistics on firewood collection and energy consumption patterns, as well as on households' socio-economic characteristics for the whole sample and for three sub-samples. Inter-village comparisons highlight noteworthy differences across groups of villages following a distribution of the ten surveyed villages along the road: 4 villages are located along the main national road, 3 villages are located along the (only) secondary road and the other 3 are remote villages with no direct access to the main road. The original survey covers 308 households. Six households failed to report information for one of the explanatory variables used in the empirical analysis below (with no systematic bias for any specific variable). 29 additional households did not report enough information on firewood collection, although half of them declared collecting firewood for their own consumption. This is consistent with the fact that in the absence of a firewood market, a very large majority of households collect their own firewood in the township. All together less than 5% of the surveyed households do not declare collecting firewood and among these households, a few declare purchasing firewood while others declare receiving firewood as a gift. Given the above restrictions on missing information, the final sample size is 273 households.

As firewood can be easily found at walking distance from all villages in the survey area, it is a widely available primary source of energy, and it is used by all surveyed households for both cooking and heating needs. The average weekly consumption of firewood per household varies a lot between winter and summer: the weekly consumption is 3 times higher during winter, which reflects the importance of firewood use for heating. Still, the weekly consumption of 62kg during summer indicates that firewood is also a cooking fuel source for households in the area. The average daily consumption of firewood of 31 *jin* is 30% higher than the average firewood collected in Chen *et al.*

---

4 rural counties. Each county is composed of several townships, themselves composed of several villages.

(2006)'s sample, which is consistent with the fact that households in Labagoumen township use firewood for both cooking and heating[4].

Coal is by far the most widely used substitute to wood. About two-thirds of the surveyed households use coal as another energy source, with however clear differences across villages. Table 1 shows that remote villages are significantly less diversified. Indeed, the share drops to only half of the households in remote villages, whereas it goes up to 70% in villages located along the main or the secondary road. Modern, environment-friendly fuel sources are barely used in the township. As an example, only 1.9% and 1.1% of the households use respectively gas and electricity for heating.

Table 1 also reviews firewood collection characteristics. A large majority of households reports the household head as the principal collector (89%)[5]. The average number of collections per year is close to 20 and the collection time is about 5 hours. Average unitary firewood collection time of 0.03 hours per kg is in line with Amacher *et al.* (1999)'s findings for a mid-hill region in Nepal, whose geographical characteristics might be close to Labagoumen characteristics. The average distance to the collection site is about 2km and almost 1 hour. There are significant differences in forest access for villages located along the main road as compared to other villages. Hence, households in these villages collect firewood in sites much farther from their home, and spend significantly more time in collecting firewood (although less frequently) than households in other villages, indicating a more limited access to forest resources in these villages. On the other hand, as mentioned above, they use significantly more coal than remote villages, where market access is much more limited due to bad road conditions. The situation of villages along the secondary road is intermediate in that households consume significantly more firewood than in other villages. Forest access in these villages is rather good with a lower distance to forest as well as easiness to access, which allows more frequent firewood collection. Last, only 17% of the households declare collecting firewood in forests, with the

[4] The three villages surveyed by Chen *et al.* (2006) are located on the southeastern part of China where the mild climate makes heating not fully necessary during winter. The gap is also similar to the overall gap in annual rural household per capita energy consumption observed between northern China and southern China (Zhou *et al.*, 2008).

[5] As household heads are mostly men, this observation is consistent with Chen *et al.* (2006)'s observation that only men collect firewood in southern China. In an international perspective though, this finding is in sharp contrast with the high involvement of women or children in firewood collection usually found in Nepal (Baland *et al.*, 2010; Cooke, 1998) or India (Heltberg *et al.*, 2000).

majority collecting either from hedges or from isolated bushes. However, field observation reveals that firewood collection from "hedges" tends to concern young oaks, on the edge of forests, turning what could have become oak forests into coppices, which is certainly also detrimental to the natural regeneration and expansion of forest in the area.

Households' characteristics summarized in Table 2 reflect the poor socio-economic condition of the township. Until recently, the agricultural sector alone was employing most of the active population, and the area was relying on subsistence agriculture (Démurger *et al.*, 2010). Agriculture remains the primary source of income for households. Most households are engaged in agricultural activities, and on average only 0.4 adult members are engaged in non-agricultural activity in a household. As for agriculture, the number of livestock owned by the household averages 2.4 and the farm size is very small. The mean cultivated farm size is less than half a hectare, with a maximum at about 1.7 ha. Although villagers living along the main road have smaller farmland, their livestock is significantly higher than in other villages, which may indicate a higher level of households capital and wealth in villages located along the main road.

Socio-demographic characteristics show no striking differences across villages. The average household size is 3.3 with a maximum of 6, and the average age is slightly above 41 years. Education levels are very low: the average number of years of education for adult members is only 5 years and for household heads, it is less than 6 years of education. This means that the average schooling level of household heads in the township does not exceed primary school. Moreover, no household reports an education level higher than senior high school.

## 3. Firewood household demand: theoretical background

The demand for wood as a source of energy has been analyzed theoretically and empirically through various complementary angles, including the environmental Kuznets curve (Foster & Rosenzweig, 2003), the poverty-environment hypothesis (Duraiappah, 1998; López, 1998; Mäler, 1998; Wunder, 2001; Zwane, 2007), the energy ladder hypothesis (Arnold *et al.*, 2006), the estimation of Engel curves and agricultural households' models (Amacher *et al.*, 1993; 1996; 1999; Baland *et al.*, 2010; Gundimeda & Köhlin, 2008; Heltberg *et al.*, 2000; Mekonnen, 1999), and village computable general equilibrium (CGE) models (Shi *et al.*, 2009). The main economic dimensions highlighted in the literature on the relationship between poverty and forest degradation through firewood collection include income, opportunity costs, preferences, market imperfections, institutional weaknesses and credit constraints (Arnold *et al.*, 2003; 2006; Cooke *et al.*, 2008; Duraiappah, 1998; Wunder, 2001).

The theoretical background for our estimations builds on the household model developed by Chen *et al.* (2006) for three villages in Jiangxi province. Their model mainly draws from Heltberg *et al.* (2000), with three major changes: the firewood substitute is a commercial energy (coal) rather than a private non-marketed energy (animal dung or crop residues), there is no market for firewood (and as a consequence, no observable market price for firewood), and there is no distinction between male and female labor, especially for firewood collection.

As documented in section 2, energy consumption patterns in Labagoumen show strong similarities with Chen *et al.* (2006) model characteristics, except that firewood is only used for cooking in Jiangxi province. First, the main energy substitute for firewood in Labagoumen is coal, which is only available at a market price. We thus restrict the analysis to firewood and coal consumption. Second, firewood collection can be reasonably assumed to be made only for the purpose of the household own consumption, and in the absence of a market for firewood, production and consumption are made simultaneously. Therefore, the household behavior can be modeled through a non-separable household model in which the household-specific shadow price of firewood corresponds to its unobserved shadow cost of collection (Amacher *et al.*, 1996; Baland *et al.*, 2010) and thus depends on the opportunity cost of family time used in collection. In our specific case, households do not employ hired labor to collect firewood, and as noted above, firewood collection is mostly made by household heads. Hence, as stated by Amacher *et al.* (1996), "the willingness to collect firewood depends on each household's valuation of time and its preference regarding the leisure-labor trade-off" (p. 1726).

In a situation where households engage in crop production, off-farm work and firewood collection, the utility derived from their consumption of goods and leisure can be written as follows:

$$U = U(C_E, C_X, C_L; z^C)$$

where $C_E$ stands for the consumption of goods requiring energy (basically cooking or heating), $C_X$ for the consumption of other goods and $C_L$ for leisure. $z^C$ is the vector of the household's characteristics likely to influence its preferences (wealth, household size, etc.).

Household utility maximization is subject to a budget constraint determined by household consumption expenditures and income:

$$p_X C_X + p_{Co} C_{Co} = R$$

where $p_X$ and $p_{Co}$ are market prices respectively for goods $X$ and for coal, $C_{Co}$ is the amount of coal consumed and $R$ is the total (on and off-farm) income[6].

The consumption of goods requiring energy ($C_E$) depends primarily on the consumption of energy, either firewood or coal[7]. Since there is no market for firewood, firewood consumption as an intermediate input to household utility equals firewood production, which in turn mainly depends on the family time spent on firewood collection (firewood collection being a labor-intensive activity).

The maximization process leads to reduced-form equations for the quantity of firewood and coal consumed as well as for the amount of time spent collecting. Given the non-separable structure of the model, endogenous variables depend on all exogenous factors, irrespective of whether they are related to consumption or production decisions. Exogenous variables comprise household characteristics and endowments pertaining to consumption and productive activities, forest access conditions, prices of goods, and off-farm wages. As pointed out by Heltberg *et al.* (2000), "equations are independent and it is not necessary to estimate the full system of all endogenous variables" (p. 221).

---

[6] Total income can be further decomposed into income from agricultural activities (as the price of agricultural products multiplied by the quantity sold) and income from off-farm activities (as the exogenous wage rate multiplied by labor time spent on off-farm work), as in Heltberg *et al.* (2000) and in Chen *et al.* (2006).

[7] In their models, Amacher *et al.* (1996), Chen *et al.* (2006), and Heltberg *et al.* (2000) also include the characteristics of the household's stove in the production function of the energy good. We do not consider this variable here since we do not have information on the use of improved stove at the household level. One of the potential shortcomings of our analysis may therefore be that it fails to account for the impact of the use of improved stoves or end-use technologies as a potential for reducing pressure on forest resources. However, in their case study of three villages in southern China, Chen *et al.* (2006) find no evidence to support this hypothesis. Moreover, field observation validates the hypothesis of a common stove technology across households in Labagoumen township.

In what follows, we will focus on firewood consumption decision and on substitution behavior, by estimating separate firewood consumption and energy substitution choice equations. In poor regions, it is commonly observed that even households using more expensive alternative energy sources still use firewood. As income increases, two effects may be at stake in determining the substitution choice: on one hand, the income effect tends to show increasing firewood consumption with rising income and on the other hand, the substitution effect tends to lead to decreasing firewood consumption as rising income allows for a growing use of alternative energy sources. At the macro level, the energy transition in rural China has been first driven by an income effect during the 1980s and the substitution effect started to overcome the income effect in the 1990s (Jiang & O'Neill, 2004). We further investigate the issue at the household level in the next section.

## 4. Firewood consumption in Labagoumen: income versus substitution effect

### *4.1. Measurement and specification issues*

Micro-economic studies on the determinants of firewood consumption in rural areas usually use 3 different types of measures for households' living standards: households' income, households' total expenditures, or a measure of households' wealth or assets. As discussed in Baland *et al.* (2010), a number of methodological issues including endogeneity and measurement error problems arise when income or consumption variables are used for measuring living standards. Moreover, in our case, these measures present additional shortcomings. As for income, since self-consumption is fairly important in rural areas in China, monetary income only cannot properly account for the true level of household income[8]. An alternative might be to use households' expenditures as more reflective of long-term income. However, this measure cannot either properly account for the distribution of wealth across households when saving rates are high and unequally distributed. In most rural areas in China, where poverty is still persisting, insurance and credit markets are absent or imperfect (Jalan & Ravallion, 2001). Hence, while facing substantial risks, rural households have limited access to formal insurance

[8] Although the survey includes information on household income, self-consumption is not reported and some answers related to income are subject to large measurement errors.

mechanisms and must consequently turn to savings, as reflected by the particularly high saving rates in China[9].

A third approach consists in using household assets as a measure of wealth. In rural areas, households' assets can be accounted for through various channels that reflect both productive and non-productive assets. In what follows, we resort to 4 different variables (farmland, livestock, wealth index, and dwelling size) that aim to measure the income effect on firewood consumption. Following Amacher *et al.* (1999), Heltberg *et al.* (2000) and Baland *et al.* (2010), we introduce productive assets in the form of farmland size and the livestock owned by the household. We measure the level of non-productive assets by introducing the household dwelling size per capita, and by computing a household wealth index[10] as a linear combination of durable assets indicators through factor analysis (Sahn & Stifel, 2003)[11]. This wealth composite index is meant to measure an *ex ante* level of wealth that is supposedly less subject to endogeneity problems than a simple measure of household income or expenditure. A set of seven ordinal indicators is selected to reflect the level of household durable assets: the ownership of a bicycle, a motorcycle, a color TV, a radio, a refrigerator or a washing machine, and the equipment of the dwelling with a bathroom. The estimated scoring coefficients from the factor analysis and the observed frequency relative to these assets are given in the Appendix. As expected, the weights are all positive since all the variables measure "access to assets" (rather than a lack of assets). The higher weights found for the ownership of durable goods such as a color TV, a washing machine, or a refrigerator indicate that these goods are the most effective in stratifying wealth groups in our sample.

We use the household wealth index in two ways. First, we introduce it as a direct explanatory variable for firewood consumption and substitution choices. Second, we use it to split the sample into four categories representing different levels of wealth (poorest, poor, middle, and wealthiest), which

[9] For the period from 1996 to 2004, the saving rates of rural households in China averaged 26.5% (Horioka & Wan, 2007).
[10] In the literature on firewood consumption, a few papers also use a measure of wealth, but mostly through a simple count of households' assets such as land owned, livestock and non-farm business assets (e.g. Baland *et al.*; 2010; Chen *et al.*, 2006; Pattanayak *et al.*, 2004).
[11] A brief description of the methodology is given in Démurger *et al.* (2010). The interested reader can also refer to Sahn & Stifel (2003) for a detailed discussion of the benefits and drawbacks of the approach as compared to a principal component analysis approach.

will be used in interaction terms with collection time. Each household is grouped into one of the four categories, based on the computed wealth index score. As our focus is on the impact of different levels of wealth on firewood consumption, threshold levels are chosen according to means rather than median or centiles. We first split the sample into 2 groups above and below the mean of the household wealth indicator, and we further split each sub-group into 2 groups, again above and below the mean for the new sub-sample.

Table 3 provides estimation results on the determinants of firewood consumption in the township of Labagoumen. The explained variable is the household daily firewood consumption for heating and cooking (in *jin*)[12] and explanatory variables include indicators of households' assets, a price proxy, and several demographic characteristics representing household needs and preferences. Moreover, we control for unobserved characteristics at the village level by introducing village fixed-effects[13]. In the absence of relevant information at the individual level, village-fixed effects are also assumed to control for forest access conditions and off-farm wages. Since all households in our sample report a strictly positive consumption of firewood, no censoring is involved. Hence, least-square estimations correcting for heteroskedasticity are run. Table 3 reports various specifications and shows that most results are robust to specification changes.

*4.2. Households assets and firewood consumption*

Estimations provide various interesting results on the relationship between households' assets and firewood consumption in Labagoumen township. First, as indicated in models (1) to (5) in Table 3, we find strong evidence in favor of an inverse relationship between wealth and firewood consumption. The negative and significant coefficient associated with the wealth index indicates that wealthier households consume less firewood than the poorest, all other things being equal. Moreover, to account for non-linearity in the relationship between income and firewood consumption, we also

[12] A daily consumption expressed in *jin* allows for a more straightforward comparison with Chen *et al.* (2006) since they estimate the amount of firewood collected in *jin* per day.

[13] As argued by Baland *et al.* (2010), "geography or climate variations may jointly affect firewood availability, asset ownership and living standards", and these village-specific characteristics are not properly accounted for in most studies on the relationship between income and firewood consumption. Chen *et al.* (2006) also introduce a

introduce the square of the household wealth indicator, which is significant and positive. These findings provide interesting evidence on the impact of income growth on firewood consumption and the potentially positive effect of the enrichment of rural population on forest resources. Indeed, they suggest that in Labagoumen township, firewood is an inferior good for all households, which supports the energy ladder hypothesis. However, the convex form of the relationship reveals some "floor effect"[14], which suggests that for wealthier households, the substitution effect that leads households to turn away from firewood as their income increases is less prominent. In other words, this result implies that there is a level below which the consumption of firewood cannot be reduced. It is consistent with the observation that in our sample all households use firewood, whatever their wealth level. One of the mechanisms that could explain this result is that households substitute coal to firewood for heating when they get richer, but even at higher living standards they keep using their traditional way of cooking, which requires some firewood to be consumed.

Microeconomic studies of rural households' firewood demand or supply in developing countries find rather mixed evidence on the relationship between income and firewood consumption. Most papers tend to find a small and negative or insignificant income elasticity of firewood consumption (Cooke *et al.*, 2008; Hyde & Köhlin, 2000), which entails a rather limited impact of poverty reduction on forest degradation. Using household data on rural Nepal, Baland *et al.* (2010) even find evidence of a positive relationship between income and firewood collection, poorer households being found to collect less firewood than wealthier households within the same village. However, Nepalese households studied by Baland *et al.* (2010) are actually in the opposite situation as compared to our case study since firewood has a widespread lower substitute (dung) there. Applying a reverse reasoning in which firewood is a "superior" substitute to dung can therefore explain the difference in signs. As for China, Chen *et al.* (2006) find a significant negative wealth impact on the consumption of firewood for the households in the two relatively rich villages, but not for the households in the poorer village where coal is not available as a substitute. Using a different

---

village dummy to capture village level differences in the price of various commodities (including coal) and off-farm wages.

[14] Since the turning point occurs at the top end of the distribution, the increasing part of the U shape does not need to be interpreted.

methodology, Shi *et al.* (2009) even find a positive wealth effect for households in the poorest village, and conclude that "the positive impact of more food consumption on fuelwood collection more than compensates the higher leisure demand associated with higher incomes" (p. 357) for households in that remote village. Our sample's villages being wealthier than Chen *et al.* (2006)'s villages[15], our results only corroborate part of their findings, but they provide further evidence by establishing varying responses along the wealth distribution.

Other indicators of households' assets provide additional channels on the relationship between poverty and firewood consumption. First, the household dwelling size per capita has a significant negative effect on firewood consumption, which corroborates the finding that wealthier households tend to consume less wood. Other things equal, a 10% increase in the household dwelling size per capita leads to a 1.7% reduction in firewood consumption. Second, productive assets are found to have differentiated effects on firewood consumption. On one hand, a larger livestock is found to significantly reduce firewood consumption, by a small amount, though. On the other hand, an increase in the size of landholdings is associated with a significant increase in firewood consumption. The elasticity evaluated at the mean indicates that when total farmland increases by 10%, firewood consumption increases by 1.8%. Chen *et al.* (2006) report similar findings on southern China, which they relate to the fact that larger landowners earn more agricultural income, which induces more food consumption and more energy consumption. In Labagoumen township, our data do not allow separating energy consumption for heating and cooking, but a similar interpretation may certainly hold in a context where most households live in poverty.

### *4.3. Testing for the own-price effect*

Besides income-related indicators, another important effect to be measured when exploring firewood consumption determinants is the own-price effect. As stated by Arnold *et al.* (2003), "how responsive fuelwood demand is to its own price is at the heart of the fuelwood scarcity issue" (p. 10).

[15] Macroeconomic figures suggest that the households in Chen *et al.* (2006) are poorer on average than the households in our sample. Indeed, the villages examined by Chen *et al.* (2006) have per capita incomes lower than 2000 yuan in 2000 (Heerink *et al.,* 2007) while per capita GDP in Labagoumen township was above 5,000 in 1999.

To measure the shadow price of fuel, we follow Mekkonen (1999) and Baland *et al.* (2010) by introducing firewood collection time (expressed in hours per kg) interacted with household wealth (or wealth categories). Therefore, the opportunity cost of firewood collection, used as a proxy for firewood price[16], corresponds to the collection time multiplied by the opportunity (shadow) cost of time, which we assume proportional to household wealth[17].

As shown in Table 3, we find non-interacted collection time not significant (model (2)), which suggests an overall inelastic household's response to collection time[18]. However, we find negative and significant coefficients for the interaction term with the wealth index, as well as with the wealthiest group of households, which indicates that the opportunity cost of firewood collection, or the own-price effect, increases with higher living standards, whereas it is not significant for the poorest households. This suggests that although firewood demand is not found to be much responsive to increased scarcity for the whole population, the substitution effect occurs at higher level of wealth. Wealthy households have an additional incentive to substitute when collection time (or scarcity) increases.

*4.4. Other firewood consumption determinants*

Additional explanatory variables include household needs and preferences, captured by the household size, the household average age, the average education level of adult members, and the non-agricultural labor force in the household. Out of these 4 variables, only the last one is found to have no significant impact on firewood consumption. Household size positively affects firewood consumption. This finding is consistent with expectations given the fact that, as the number of members in a household increases, energy demand also increases (and possibly also the supply of labor for collection). The positive and significant coefficient for the household average age gives support to the idea that older people tend to perpetuate traditional heating and cooking habits more than younger households and consequently tend to use firewood more intensively. There may also be a demand

[16] In the absence of a market for fuelwood, agricultural household models show that collection time is a good measure of the household opportunity cost of firewood (see Amacher *et al.,* 1993).
[17] Non-interacted collection time is also used in Amacher *et al.* (1993) and Heltberg *et al.* (2000) as a proxy for labor opportunity cost. However, Baland *et al.* (2010) argue that relying on additive specifications is not appropriate to provide estimates of the income and the substitution effects.

effect of age in that the elderly tend to spend more time at home and are thus more likely to consume more firewood, especially for heating during winter. On the other hand, firewood consumption is negatively related to the average education level of adult members, a variable that can be interpreted as reflecting the impact of "modernity" on fuel use choices (Baland *et al.*, 2010; Chen *et al.*, 2006). By raising the shadow price of collection time, a higher level of education may contribute to changing the energy use behavior, and in our case, further reinforce the effect of wealth increase.

### *4.5. The determinants of substitution choice*

Estimations on the determinants of household firewood consumption have shown that a key issue in the studied township is that moving along the wealth scale affects the household decision to use alternative energy sources and to reduce firewood consumption. To further investigate the impact of wealth on households' substitution choice, we estimate a "substitution choice" equation using a Probit model on the use of coal for cooking and/or heating. Table 4 reports the marginal effects of various specifications for the Probit estimates. Unsurprisingly, all the estimations provide evidence of wealth as a key determinant of coal consumption and support the hypothesis for coal being a substitute to firewood. Coal consumption is rising and concave in wealth, with again a turning point occurring at the top of the distribution. On the other hand, no significant relationship is found between coal consumption and firewood collection time interacted with wealth or the four wealth categories, although the positive sign found for the wealthiest categories may plead in favor of the hypothesis that when the household opportunity cost of time increases, households tend to shift to coal as an additional source of energy. Finally, we find that the use of coal also depends positively and significantly on the average education level of adult members as well as on whether the household has children or siblings living out of the village. These two effects reflect differences in household preferences. More educated people tend to value the use of modern energy sources and may be less reluctant to changes in heating and cooking habits. The households' family network living outside the

[18] Amacher *et al.* (1993) and Heltberg *et al.* (2000) also find inelastic collection time respectively for Nepal and India.

village (and possibly in neighboring cities) may also influence fuel consumption choice towards modern energies.

Compared to the empirical literature on firewood consumption in South Asia or Africa, our case study presents some characteristics about fuel substitution that are worth mentioning. In particular, most papers that compare firewood consumption with other energy sources emphasize the substitution patterns between firewood and lower substitutes, such as animal dung or crop residues. Although the use of such substitutes may be less detrimental to forests, there is a trade-off between using them as agricultural inputs and burning them for fuel (Heltberg *et al.*, 2000). In our case study, the substitution pattern is radically different in terms of agricultural and environmental impact since the main substitute is coal. Although substitution to coal might help reducing pressure upon forest resources, an increased use of coal in rural China might be even more damaging for the environment in terms of water and air pollution. In this respect, providing cleaner energy sources (through biogas, the use of improved stoves, etc.) in rural China where the process of substitution has already started is certainly crucial to limit further environmental degradation.

## 5. Conclusion

Since the implementation of the Natural Forest Protection Program (NFPP) logging ban in 1998, deforestation has been fairly controlled in China's natural forests. However, limiting forest degradation and stimulating afforestation dynamics remain important issues as poor rural residents are still collecting firewood and grazing cattle around forests. In this paper, we address the question of the linkages between firewood consumption and economic wealth through a case study of a poor rural township in China. We contribute to the on-going debate on rural poverty and forest degradation and show that in rural China, poverty reduction may be a pre-condition for forest protection. While the empirical literature tends to find no strong relationship between income and firewood consumption, our results corroborate Chen *et al.* (2006) findings on a region in China radically different with respect to economic, geographic, and ecological conditions. We explore further the issue by providing a more in-depth analysis of the wealth and price effects.

Using original household survey data, we find that income is a key factor in explaining energy use behavior and the substitution from private fuels to commercial energy sources. Our estimations provide strong evidence in favor of the poverty-environment hypothesis, wealth being a significant and negative determinant of household firewood consumption. Firewood can therefore be considered as an inferior good for the whole population in the rural area under study, with rising wealth leading to a higher degree of substitution and therefore to a decreasing firewood consumption. Further evidence on the relationship shows that at the top of the wealth distribution, there might be some floor effect in the decreasing firewood consumption, and that moving away from traditional ways of cooking may be not so easy in the area, even at higher living standards. Hence, wealthier households seem to be less income responsive, which is consistent with the fact that no household has completely turned away from firewood as an energy source. Wealthier households may not be rich enough to afford changing stoves, or may be still reluctant to change their traditional cooking and heating habits.

Besides the income effect, our analysis also shows the importance of the own-price effect in explaining firewood consumption behavior. Hence, we found the opportunity cost of firewood collection to be significant and negative for the wealthiest group of households, indicating that the price effect gains importance with rising incomes. Finally, "modernization" in the form of increasing education or family network is also found to be a key factor in the energy consumption behavior, especially when dealing with energy source switching behavior.

The main policy implications of our findings are the following. Up to now, the Chinese authorities have mostly answered the question of forest protection by imposing coercive measures on local population such as a restricted access to forest resources and the ban on grazing cattle, which raises the issue of the distributional effect of such measures on already poor and vulnerable households. Our analysis shows that poor people are strongly dependent upon forest resources. In this perspective, policies that intend to have an impact on forest degradation should be based on a careful analysis of local household behavior towards forest resources.

Imposing coercive measures without accompanying measures might lead to an increase in rural poverty, and our results suggest that the poorest part of the population would be the most badly hit by a limitation in the access to forest resources. As a consequence, this would not only lead to an increase in poverty but also to a deepening of poverty in vulnerable areas. The induced increase in polarization and social tensions may in turn induce potential counter-productive effects on environmental protection as poorer households may turn to illegal firewood collection practices that would be even more detrimental to forest resources.

Our results also suggest that forest protection policies in China may be successfully coupled with poverty reduction programs if these programs are thought in terms of finetuning associating different measures with different income groups. First, anti-poverty policies that would effectively target the poorest households would help altering forest degradation in moving forest users along the energy ladder. Second, for wealthier households, the most effective strategy might be to help them changing their habits concerning cooking and heating, and investing in modern stoves that do not require firewood or use firewood in a more efficient way. Third, active policies should aim at encouraging diversification in energy consumption through a greater local availability of low cost and cleaner substitutes. In terms of environmental degradation, substitution to fossil coal is certainly not the most desirable answer, but experiments with producing biogas or using energy-saving stoves could be seen as encouraging changes. Recent evidence suggests that such a transition is already at stake in northern China, where modern renewable energy, including solar energy, biogas or energy-saving stoves have developed quickly in recent years, although high costs and scale limitations are affecting their expansion (Zhou *et al.*, 2008).

**References**

Adeoti, O., Idowu, D. O. O., & Falegan, T. (2001). Could fuelwood use contribute to household poverty in Nigeria?. *Biomass & Bioenergy*, 21, 205-210.

Adhikari, B., Di Falco, S., & Lovett, J. C. (2004). Household characteristics and forest dependency: evidence from common property forest management in Nepal. *Ecological Economics*, 48(2), 245-257.

Amacher, G., Hyde, W., & Joshee, B. (1993). Joint production and consumption in traditional households: fuelwood and crop residues in two districts of Nepal. *Journal of Development Studies*, 30(1), 206-225.

Amacher, G., Hyde, W., & Kanel, K.R. (1996). Household fuelwood demand and supply in Nepal's tarai and mid-hills: choice between cash outlays and labour opportunity. *World Development*, 24(11), 1725-1736.

Amacher, G., Hyde, W., & Kanel, K.R. (1999). Nepali fuelwood production and consumption: regional and household distinctions, substitution, and successful intervention. *Journal of Development Studies*, 35(4), 138-63.

Anderson, D., & Fishwick, R. (1984). Fuelwood consumption and deforestation in African countries. *World Bank Staff Working Paper* No. 704, Washington DC: World Bank.

Arnold, M., Köhlin, G., & Persson, R. (2006). Woodfuels, Livelihoods, and Policy Interventions: Changing Perspectives. *World Development*, 34(3), 596-611.

Arnold, M., Köhlin, G., Persson, R., & Sheperd, G. (2003). Fuelwood Revisited: What Has Changed in the Last Decade? *Center for International Forestry Research Occasional Paper* No. 39, Jakarta.

Baland, J-M., Bardhan, P., Das, S., Mookherjee, D., & Sarkar, R. (2010). The Environmental Impact of Poverty: Evidence from Firewood Collection in Rural Nepal, *Economic Development and Cultural Change*, 59(1), forthcoming.

Bruce, N., Perez-Padilla, R., & Albalak, R. (2000). Indoor Air Pollution in Developing Countries: a Major Environmental and Public Health Challenge. *Bulletin of the World Health Organization*, 78(9), 1078-92.

Cavendish, W. (2000). Empirical Regularities in the Poverty-Environment Relationship of African Rural Households. *World Development*, 28 (11), 1979-2003.

Chen, L., Heerink, N., & Van den Berg, M. (2006). Energy consumption in rural China: A household model for three villages in Jiangxi Province. *Ecological Economics*, 58(2), 407-420.

Cooke, P. (1998). Intrahousehold Labor Allocation Responses to Environmental Good Scarcity: A Case Study of Nepal. *Economic Development and Cultural Change*, 46, 807-830.

Cooke, P., Hyde, W., & Köhlin, G. (2008). Fuelwood, forests and community management - Evidence from household studies. *Environment and Development Economics*, 13, 103–135.

Démurger, S., Hou, Y., & Yang, W. (2009). Forest Management Policies and Resource Balance in China: An Assessment of the Current Situation. *The Journal of Environment & Development*, 18(1), 17-41.

Démurger, S., Fournier, M., & Yang, W. (2010). Rural households' decisions towards income diversification: Evidence from a township in northern China. *China Economic Review*, 21(S1), S32-S44.

Dewees, P. A. (1989). The Woodfuel Crisis Reconsidered: Observations on the Dynamics of Abundance and Scarcity. *World Development*, 17(8), 1159-1172.

Duraiappah, A. K. (1996). Poverty and Environmental Degradation: A Literature Review and Analysis. CREED *Working Paper Series* No.8, International Institute for Environment and Development, London.

Duraiappah, A. K. (1998). Poverty and Environmental Degradation: A Review and Analysis of the Nexus. *World Development*, 26(12), 2169-2179.

Eckholm, E. (1975). The Other Energy Crisis: Fuelwood. *Worldwatch Paper* 1, Worldwatch Institute, Washington DC.

Foster, A. D., & Rosenzweig, M. R. (2003). Economic growth and the rise of forests. *The Quarterly Journal of Economics*, 118(2), 301-637.

Gundimeda, H., & Köhlin, G. (2008). Fuel demand elasticies for energy and environment studies: Indian sample survey evidence. *Energy Economics*, 30(2), 517-546.

Heerink, N., Qu, F., Kuiper, M., Shi, X., & Tan, S. (2007). Policy reforms, rice production and sustainable land use in China: A macro-micro analysis. *Agricultural Systems*, 94, 784-800.

Heltberg, R., Arndt, T. C., & Sekhar, N. U. (2000). Fuelwood consumption and forest degradation: a household model for domestic energy substitution in rural India. *Land Economics*, 76(2), 213-232.

Horioka, C., & Wan, Y. (2007). The Determinants of Household Saving in China: A Dynamic Panel Analysis of Provincial Data. *Journal of Money, Credit and Banking*, 39(8), 2077-2096.

Hyde, W.F., & Köhlin, G. (2000). Social forestry reconsidered. *Silva Fennica*, 34(3), 285-314.

Jiang, L., & O'Neill, B. C. (2004). The energy transition in rural China. *International Journal of Global Energy Issues*, 21(1-2), 2-26.

Jalan, J., & Ravallion, M. (2001). Behavioral Responses to Risk in Rural China. *Journal of Development Economics*, 66(1), 23-49.

Leach, M., & Mearns, R. (1988). *Beyond the Woodfuel Crisis: People, Land and Trees in Africa*, Earthscan Publications, London.

López, R. (1998). Where Development Can or Cannot Go: The Role of Poverty-Environment Linkages. In B. Pleskovic, & J. Stiglitz (Eds.), *1997 Annual World Bank Conference on Development Economics*. Washington DC: World Bank.

Mäler, K. G. (1998). Environment, Poverty and Economic Growth. In B. Pleskovic, & J. Stiglitz (Eds.), *1997 Annual World Bank Conference on Development Economics*. Washington DC: World Bank.

Mekonnen, A. (1999). Rural Household Biomass Fuel Production and Consumption in Ethiopia: A Case Study. *Journal of Forest Economics*, 5(1), 69-97.

Pattanayak, S. K., Sills, E. O., & Kramer, R. A. (2004). Seeing the forest for the fuel. *Environment and Development Economics*, 9, 155-179.

Reddy, B. S. (2003). Overcoming the energy efficiency gap in India's household sector. *Energy Policy*, 31, 1117-1127.

Sahn, D.E., & Stifel, D. (2003). Exploring alternative measures of welfare in the absence of expenditure data. *Review of Income and Wealth*, 49(4), 463-489.

Shi, X., Heerink, N., & Qu, F. (2009). The role of off-farm employment in the rural energy consumption transition - A village-level analysis in Jiangxi Province, China. *China Economic Review*, 20(2), 350-359.

Shyamsundar, P., & Kramer, R. A. (1996). Tropical forest protection: An empirical analysis of the costs borne by local people. *Journal of Environmental Economics and Management*, 31, 129-144.

Trossero, M. A. (2002). Wood energy: the way ahead. *Unasylva* 211, 53, 3-12.

Wang, X., & Feng, Z. (2001). Rural household energy consumption with the economic development in China: stages and characteristics indices. *Energy Policy*, 29, 1391-1397.

World Bank (2003). *World Development Report: Sustainable Development in a Dynamic World*, Oxford: Oxford University Press.

Wunder, S. (2001). Poverty Alleviation and Tropical Forests – What Scope for Synergies? *World Development*, 29(11), 1817-1833.

Zhou, Z., Wu W., Chen, Q., & Chen, S. (2008). Study on sustainable development of rural household energy in northern China, *Renewable and Sustainable Energy Reviews*, 12, 2227–2239.

Zwane, A. P. (2007). Does poverty constrain deforestation? Econometric evidence from Peru. *Journal of Development Economics*, 84(1), 330-349.

## Table 1 – Energy consumption characteristics in the sample villages

| | *Total* | *Villages along the main road* | *Villages along the secondary road* | *Remote villages* |
|---|---|---|---|---|
| Annual firewood consumption (ton/year) | 5.757 (4.097) | 5.218* (3.758) | 6.509* (4.231) | 5.594 (4.271) |
| Weekly firewood consumption during winter (kg/week) | 188.6 (128.6) | 175.6* (125.0) | 206.8* (129.0) | 184.8 (131.8) |
| Weekly firewood consumption during summer (kg/week) | 62.22 (58.57) | 53.83* (54.81) | 74.19* (59.65) | 59.32 (60.35) |
| Daily firewood consumption (jin/day) | 31.54 (22.45) | 28.59* (20.59) | 35.67* (23.18) | 30.65 (23.40) |
| Average annual number of firewood collection journeys | 18.63 (20.74) | 14.05* (15.24) | 22.62* (25.05) | 19.73 (20.40) |
| Average collection time per journey (h) | 5.282 (2.215) | 5.782* (2.540) | 5.233 (1.902) | 4.720* (1.974) |
| Collection time (h) per kg of collected wood | 0.0318 (0.0311) | 0.0295 (0.0344) | 0.0322 (0.0259) | 0.0344 (0.0322) |
| Household head as the principal collector for firewood | 88.6% | 89.1% | 88.9% | 87.8% |
| Forest as the main collection site | 17.2% | 18.4% | 15.9% | 17.3% |
| Distance to the collection site (km) | 2.174 (1.386) | 2.719* (1.634) | 1.837* (1.200) | 1.893* (1.017) |
| Coal consumption (1=yes) | 64.8% | 70.3%* | 70.0%* | 52.4%* |
| **Number of surveyed households** | 273 | 101 | 90 | 82 |

*Source*: Household survey conducted by the authors in 2001.
*Notes*: Mean (standard deviation). Mean tests are performed for each variable and each group of villages in a comparison with the other two groups of villages. A star (*) indicates a significant difference. The conversion for Chinese weight unit is 1 *jin* = 500g.

## Table 2 – Households characteristics in the sample villages

| | ***Total*** | ***Villages along the main road*** | ***Villages along the secondary road*** | ***Remote villages*** |
|---|---|---|---|---|
| Household size (persons) | 3.256<br>(1.057) | 3.158<br>(0.924) | 3.511*<br>(1.134) | 3.098*<br>(1.084) |
| Household average age (years) | 41.76<br>(14.63) | 40.85<br>(14.58) | 40.57<br>(14.51) | 44.19*<br>(14.71) |
| Average education level of adult members (years) | 5.153<br>(2.672) | 5.430<br>(2.922) | 5.002<br>(2.685) | 4.978<br>(2.316) |
| Household head education level (years) | 5.927<br>(3.300) | 5.980<br>(3.371) | 5.828<br>(3.518) | 5.970<br>(2.986) |
| Non-agricultural labor force (persons) | 0.377<br>(0.702) | 0.267*<br>(0.598) | 0.533*<br>(0.851) | 0.341<br>(0.613) |
| Farmland size (*mu*) | 6.516<br>(4.132) | 6.065*<br>(3.845) | 6.727<br>(4.331) | 6.841<br>(4.250) |
| Livestock owned by the household | 2.407<br>(17.64) | 4.337*<br>(27.96) | 1.622<br>(7.425) | 0.890<br>(3.337) |
| Dwelling size per capita ($m^2$) | 22.84<br>(11.98) | 24.72*<br>(14.88) | 20.37*<br>(8.445) | 23.25<br>(10.91) |
| **Number of surveyed households** | 273 | 101 | 90 | 82 |

*Source*: Household survey conducted by the authors in 2001.
*Notes*: Mean (standard deviation). Mean tests are performed for each variable and each group of villages in a comparison with the other two groups of villages. A star (*) indicates a significant difference. The conversion for Chinese area unit is 1 *mu* = 1/15 ha.

## Table 3 – Household firewood consumption determinants

| | (1) | (2) | (3) | (4) | (5) | |
|---|---|---|---|---|---|---|
| | *Parameter* | *Parameter* | *Parameter* | *Parameter* | *Parameter* | *Elasticities* |
| Wealth | -16.57*** | -15.00** | -13.47** | -11.16* | -15.37** | -0.53** |
| | (0.004) | (0.011) | (0.026) | (0.059) | (0.028) | |
| (Wealth)² | 4.178** | 4.187** | 4.284** | 4.223** | 5.638** | 0.32** |
| | (0.041) | (0.042) | (0.032) | (0.031) | (0.017) | |
| Farmland size | | 0.874** | 0.810** | 0.849** | 0.888** | 0.18** |
| | | (0.032) | (0.044) | (0.036) | (0.028) | |
| Livestock | | -0.0760** | -0.0822** | -0.0794** | -0.0847** | -0.01** |
| | | (0.029) | (0.029) | (0.043) | (0.013) | |
| Dwelling size per capita | | -0.228** | -0.247** | -0.238** | -0.230** | -0.17** |
| | | (0.022) | (0.010) | (0.013) | (0.017) | |
| Collection time (CT) | | -3.405 | | 110.9 | | |
| | | (0.943) | | (0.189) | | |
| CT * Wealth | | | -28.42* | -64.09** | | |
| | | | (0.059) | (0.010) | | |
| CT * Poorest | | | | | 27.65 | 0.01 |
| | | | | | (0.731) | |
| CT * Poor | | | | | 61.30 | 0.02 |
| | | | | | (0.383) | |
| CT * Middle | | | | | -24.59 | -0.01 |
| | | | | | (0.745) | |
| CT * Wealthiest | | | | | -178.8** | -0.03** |
| | | | | | (0.017) | |
| Household size | | 4.789** | 4.835** | 5.115** | 4.904** | 0.51** |
| | | (0.026) | (0.022) | (0.017) | (0.025) | |
| Average age | | 0.256** | 0.278** | 0.267** | 0.263** | 0.35** |
| | | (0.039) | (0.026) | (0.033) | (0.036) | |
| Average education of adult members | | -1.066** | -1.021** | -1.030** | -1.098** | -0.18** |
| | | (0.037) | (0.046) | (0.047) | (0.033) | |
| Non-agricultural labor force | | -0.972 | -1.158 | -0.992 | -1.176 | -0.01 |
| | | (0.597) | (0.506) | (0.566) | (0.504) | |
| Village fixed effects | Yes | Yes | Yes | Yes | Yes | |
| *N* | 273 | 273 | 273 | 273 | 273 | |
| $R^2$ | 0.123 | 0.252 | 0.259 | 0.268 | 0.264 | |

*Source*: Household survey conducted by the authors in 2001.
*Notes*: The dependent variable is the household daily firewood consumption for heating and cooking (in *jin*/day). The reference group for wealth categories is the "Poorest". *p*-values in parentheses.
$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$. Elasticities evaluated at the mean.

## Table 4 – Determinants of households' coal consumption – Probit estimation

| | (1)<br>*Marginal effect* | (2)<br>*Marginal effect* | (3)<br>*Marginal effect* |
|---|---|---|---|
| Wealth | 0.481*** | 0.450*** | 0.583*** |
| | (0.001) | (0.002) | (0.001) |
| (Wealth)² | -0.112** | -0.111** | -0.175*** |
| | (0.045) | (0.046) | (0.008) |
| Farmland size | -0.00426 | -0.00383 | -0.00476 |
| | (0.626) | (0.658) | (0.580) |
| Livestock | -0.000558 | -0.000418 | -0.000145 |
| | (0.690) | (0.778) | (0.933) |
| Dwelling size per capita | 0.00751** | 0.00759** | 0.00763** |
| | (0.047) | (0.037) | (0.035) |
| Collection time (CT) | 0.595 | | |
| | (0.551) | | |
| CT * Wealth | | 0.518 | |
| | | (0.284) | |
| CT * Poorest | | | 0.815 |
| | | | (0.595) |
| CT * Poor | | | -0.306 |
| | | | (0.827) |
| CT * Middle | | | -0.336 |
| | | | (0.860) |
| CT * Wealthiest | | | 6.199* |
| | | | (0.088) |
| Household size | 0.271 | 0.270 | 0.303* |
| | (0.134) | (0.122) | (0.097) |
| (Household size)² | -0.0338 | -0.0339 | -0.0383 |
| | (0.155) | (0.141) | (0.113) |
| Average age | 0.00291 | 0.00279 | 0.00333 |
| | (0.357) | (0.378) | (0.298) |
| Average education of adult members | 0.0528*** | 0.0521*** | 0.0541*** |
| | (0.001) | (0.001) | (0.001) |
| Non-agricultural labor force | -0.00969 | -0.00716 | 0.00130 |
| | (0.867) | (0.904) | (0.983) |
| Having children or siblings outside | 0.181** | 0.181** | 0.182** |
| | (0.024) | (0.023) | (0.023) |
| Village fixed effects | Yes | Yes | Yes |
| *N* | 272 | 272 | 272 |
| Predicted Prob. (at X bar) | 69.6% | 69.7% | 70.1% |
| Observed frequency | 65.1% | 65.1% | 65.1% |
| Pseudo $R^2$ | 0.256 | 0.257 | 0.263 |
| Log-likelihood | -131 | -131 | -130 |

*Source*: Household survey conducted by the authors in 2001.
*Notes*: The dependent variable is "using coal for heating and/or cooking". *p*-values in parentheses.
$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

## Appendix – Wealth composite index: scoring coefficients from factor analysis

| *Variable* | *Scoring coefficient (weight)* | *Mean* | *Standard deviation* |
|---|---|---|---|
| Own bicycle | 0.08930 | 0.7839 | 0.4123 |
| Own motorcycle | 0.17925 | 0.1685 | 0.3750 |
| Own color TV | 0.29208 | 0.6557 | 0.4760 |
| Own radio | 0.13098 | 0.3333 | 0.4723 |
| Own refrigerator | 0.23262 | 0.1722 | 0.3782 |
| Own washing machine | 0.29308 | 0.3333 | 0.4723 |
| Bathroom in the dwelling | 0.10247 | 0.0586 | 0.2353 |

*Source*: Household survey conducted by the authors in 2001.