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Collective forest tenure reform and household energy consumption: A case study in Yunnan Province, China☆

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ABSTRACT

The recent Collective Forest Tenure Reform in China has started the process of devolving forest management rights from village collectives to households since 2003. In this paper, we study the impact of the reform on rural energy consumption. Devolving forest tenure improves farmers' access to forest products on their newly acquired forestland, and is therefore expected to increase farmers' fuelwood consumption. The reform also allows farmers to adopt some revenue-enhancing forest technologies which may lead to energy switching in farmer households. Our empirical study finds that the devolution significantly increases household fuelwood consumption for both lower and higher income households; the lower income households benefit more. This is welfare-improving in places where alternative fuels are still too costly. We find limited evidence that higher income households in Yunnan begin to substitute alternative commercial fuels for fuelwood when those are available. Our findings suggest further devolution of forest rights, especially in the poor, forest-rich regions.

1. Introduction

In most developing countries, traditional biomass (e.g., wood, straw, crop residues, manure, etc.) is the main energy source for rural households. Biomass-based energy such as fuelwood is still the largest source of renewable energy, accounting for roughly 10% of world total primary energy supply (IEA, 2012). In China's less developed rural areas, where some remote households lack access to electricity and other forms of marketed fuel, biomass is the largest source of fuel for domestic heating and cooking purposes (Zhou, Wu, Chen, & Chen, 2008). Nearly 60% of rural households use fuelwood as a main energy source for cooking as of 2010 (Tang & Liao, 2014). High reliance on biomass has implications for sustainable forest management (Anderson & Fishwick, 1984; Arnold, Köhlin, & Persson, 2006; Cooke, Hyde, & Köhlin, 2008; Heltberg, Arndt, & Sekhar, 2000) and public health due to indoor air pollution (Bruce, Perez-Padilla, & Albalak, 2000).

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The extensive literature has mainly investigated the determinants of fuelwood demand and its substitution by other energy types in developing countries, for example, Amacher, Hyde, & Joshee (1993), Amacher, Hyde, & Kanel (1996) and Baland, Bardhan, Das, Mookherjee, & Sarkar (2010) in Nepal; Ekholm, Krey, Pachauri, & Riahi (2010) and Heltberg et al. (2000) in rural India; Jumbe & Angelsen (2011) in Malawi; Lee (2013) in Uganda; Pitt (1985) in Indonesia; Chen, Heerink, & Van den Berg (2006), Demurger & Fournier (2011), Shi, Heerink, & Qu (2009) and Zhang & Kotani (2012) in rural China. However, to the authors' knowledge, no previous studies have investigated how forestry policies or reforms affect household fuelwood use. In China, the new round of Collective Forest Tenure Reform started in 2003, focusing in particular on forest rights devolution, i.e., increasing the proportion of forestland managed by individual households and strengthening tenure security. This larger proportion implies a greater extent of devolution (through transfer from village collectives to household responsibility).

The main objective of this paper is to assess the impact of forest rights devolution on the consumption of a forest product – fuelwood – in a relatively poor province in southwestern China. A secondary objective is to evaluate the substitution effects between alternate sources of energy. Our inquiry extends the prior household energy literature by adding the important policy dimension of tenure, and the geographic experience beyond South Asia and East Africa. In the literature evaluating Collective Forest Tenure Reform, little is known about the impact of forest rights devolution on rural household (biomass) energy demand. We evaluate the effect of greater and lesser devolution on fuelwood consumption by comparing villages in the same province that have different levels of devolution.

Forest tenure reform ensures that the households possess the rights to their forests and the future returns to their effort in terms of labor and capital. Well-defined and secure tenure in the Chinese reform establishes an incentive for improved forest management (Qin & Xu, 2013; Xie, Berck, & Xu, 2016; Yi, Köhlin, & Xu, 2014). One would also expect that, subsequently, forest production increases, in terms of the yields of timber, bamboo, fruit, fuelwood, and other non-timber forest products. The production, collection and self-consumption of the increase in any of these products adds to the welfare of the self-consuming households. The sales of the market products contribute to household cash income and enable them to make additional purchases of all varieties of consumer goods, including fuelwood and preferred substitutes such as charcoal, coal, LPG, and electricity where available.

Using household survey data collected in 30 villages in Yunnan province, we find that household fuelwood consumption does increase with the extent of forest rights devolution. The impact on fuelwood consumption is significant and positive for both lower and higher income households, and the lower income households benefit more. We find limited evidence that higher income households in Yunnan begin to substitute alternative commercial fuels for fuelwood when those are available. In places where easy substitutes are unavailable, any tenure-induced increase in fuelwood contributes importantly to household welfare.

The remainder of the paper is organized as follows. In Section 2, we briefly introduce the background and China's forest tenure reform. Section 3 reviews the prior literature on household energy consumption. We discuss our empirical strategy in Section 4, and describe the survey area and data in Section 5. Section 6 discusses the estimation results. Conclusions and policy implications are summarized in Section 7.

2. Background: collective forests and tenure reforms in China

Forests in China are categorized into state-owned forests and collective forests, the latter of which are legally owned by village collectives. The collective forests make up 60% of the national forest volume, much of them in the South and Southwest. Historically, after the collectivization of private forests and trees of farm households in the late 1950s, the private trees around homesteads were returned to households in 1961–1962, then taken from households and given to collectives during 1966–1980 (Liu & Edmunds, 2003).

China's market reforms began with revision of the collective agricultural system in the province of Anhui in 1978. Anhui's agricultural collectives began the reform by contracting land, equipment and shares of the collectives' production quotas to individual farm households. The households were allowed to keep for themselves any production in excess of those contracted shares, which incentivized the contracting households to increase production – immediately and rapidly. Other provinces adopted the same reforms in the 1980s. Agricultural production throughout China increased 225% in only six years (Wen, 1995; Yao, 1995).

Forest reforms followed the agricultural reforms. Forest cover and standing forest volume increased, although by a smaller 25% and 35%, respectively, by 2000. However, the forest reforms were not nearly as complete as the agricultural reforms and some forest reforms were eventually rescinded.[2] The first round of private tenure reform started in the early 1980s, transferring 31 million ha of village collectively-owned forest land to 57 million households (Liu & Edmunds, 2003). However, stock declined in the forests experiencing the reform; this was attributed to a lack of clear duration or too short a contract period,[3] lack of use rights for the trees, and frequent changes in earlier policies (Xu, White, & Lele, 2010; Holden, Otsuka, and Deininger, 2013). These factors discourage a private owner's investment incentives and regeneration efforts after harvesting, and result in myopic harvesting strategies (Albers, Rozelle, & Guo, 1998; Liu & Edmunds, 2003; Yin, 1998).

The first stage forest tenure reform was then partially reversed by the government, with strict regulations on forest harvesting and use starting in the mid-1980s. Initiated in Fujian province in 2003 and endorsed by central authority from then on, villages transferred forest rights and reallocated forestland to households through national and provincial sponsored pilots Xu et al. (2010).

[2] Lin (1992) and McMillan and Naughton (1992) are the classic citations for China's agricultural reforms. Hyde, Belcher, and Xu (2003) reviewed the early forest reforms and their effects.

[3] In the 1980s tenure reform, the contract period was 5–15 years, too short for most timber species.

Observing experimental success in the pilots, the central government formulated and announced the new round of forest tenure reform in its official policy document – "*Guidelines on Fully Promoting Collective Forest Tenure System Reform*" on July 14th, 2008 (State Council, P.R.C., 2008). Village collectives were encouraged to make collective decisions on whether or not to implement the reform, according to a majority (or two-thirds) vote through village assembly or representative committee meetings. Based on the collective forest owners' reassessment and reallocations of forestland, households' forest use rights were formally documented and certified in the forestland certificates.

The general objective of the new round of forest tenure reform was to allow the transfer of responsibility for as much as 90% of the collectives' forestlands to individual households. Households eventually obtained contracts for long-term use rights to these transferred forestlands for a period ranging from 30 to 70 years. These contracts became the basis for land use certificates that can be used as collateral when applying for loans. With loans, households are able to conduct further investment in the forests or for other household productive opportunities.

The new round of forest devolution has been gradual and continues to this day. Since 2003, an increasing number of rural villages adopted the reform. The share of collective forests managed by individual households continues to increase and household management rights increasingly include the rights to transfer land. There is no doubt that households throughout China do act as if their tenure is more secure on those forest lands for which they possess long-term rights. They invest more of their labor and more of both financial and manufactured capital, and their forest production from these lands has increased as a result (Holden, Yi, et al., 2013; Qin & Xu, 2013; Xie et al., 2016; Yi et al., 2014; Holden et al.,2013).

3. Literature review

Many of the previous studies have focused on production for domestic consumption in the absence of evidence from a market for local exchange. Therefore, direct observation of value or price is often unreported and production and consumption are considered as the joint or "non-separable" activities of each participating household (Amacher et al., 1996; Angelsen, 1999; Heltberg et al., 2000). The economic literature on this experience relies on a household model approach in which collection time for fuelwood or distance to the source for fuelwood collection becomes a measure of scarcity (Amacher et al., 1996; Baland et al., 2010; Chen et al., 2006; Demurger & Fournier, 2011; Heltberg et al., 2000; Jumbe & Angelsen, 2011). It converts collection time or distance into a measure of labor effort spent to obtain the fuelwood and, therefore, a shadow wage. As collection time or distance increases, so does the labor required to obtain a unit of fuelwood. Household production decreases because the labor costs of fuelwood increase. Household consumption decreases because the scarcity value of fuelwood, a proxy for price, increases. As expected, the literature has found evidence in support of the negative effect of opportunity cost (collection time or distance to the fuelwood site) on fuelwood consumption (Amacher et al., 1996; Baland et al., 2010; Heltberg et al., 2000; Jumbe & Angelsen, 2011).

The literature has largely documented that the variation in residential energy consumption behaviors partly reflects household incomes and lifestyle changes. When income increases, there are two effects affecting households' decisions on fuelwood consumption. On the one hand, the income effects indicate that fuelwood consumption increases with household income, although at a decreasing rate—unless fuelwood is an inferior product. On the other hand, the substitution effects, consistent with the "energy ladder" hypothesis, imply that households are expected to climb up the ladder to reach the "best" energy sources as their income rises (DeFries & Pandey, 2010; Hosier & Dowd, 1987; Leach, 1992; Reddy, 1995; Van der Kroon, Brouwer, & Van Beukering, 2013). In fact, households combine several types of fuel, including both modern and traditional energy sources. Generally, households are inclined to adopt high quality fuels as their socioeconomic situation improves, which reflects an improvement in the living standards.

On the impact of household income or wealth on demand for fuelwood and its substitutes, the literature finds mixed results. Amacher, Hyde, and Kanel (1999) found that the less-well-off households were more likely to produce for local markets when prices rose above some level, while the better-off households were more likely to purchase from the markets. Demurger and Fournier (2011) and Zhang and Kotani (2012) both investigated household energy consumption using survey data in rural Beijing, but found interestingly different results. Demurger and Fournier (2011) found a significant U-shaped relationship between household wealth and fuelwood consumption. This finding supports the "energy ladder" hypothesis that fuelwood consumption decreases with household wealth, suggesting fuelwood as an inferior good. Zhang and Kotani (2012) found a significant inverted-U relationship between household income and commercial energy consumption, suggesting that increased income generally leads to increased demand for coal, electricity and LPG, but does not affect fuelwood consumption. Moreover, Baland et al. (2010) found a positive income effect on fuelwood collection for rural households in Nepal.

Regarding the impact of off-farm income on fuelwood consumption, it could be positive because of the supplement of greater off-farm income. However, because off-farm employment generally implies work in town, the impact on fuelwood consumption could also be negative, for three reasons. Firstly, greater off-farm income increases the likelihood of substituting commercial fuels. Secondly, decreased time for fuelwood collection reduces its availability in the home. Thirdly, less time at home reduces the need for cooking and heating. Shi et al. (2009) found that, for local off-farm employment, the income effect dominates the effect of decreased forest labor and results in an increase of household fuelwood consumption. For seasonal wage employment away from the native village, the negative effect of decreased labor and the positive income effect are almost equal, so that household fuelwood consumption remains essentially unchanged. In contrast, Chen et al. (2006) observed that better-educated households consume less fuelwood. The better educated are more likely to find off-farm employment, and they maybe more aware of the health issues related to indoor pollution caused by intensive use of fuelwood and other types of agricultural residues. All these observations from the prior literature are consistent with general economic expectations. We should anticipate similar observations from our analysis in Yunnan, with further insight into the effect of improved forest tenure.

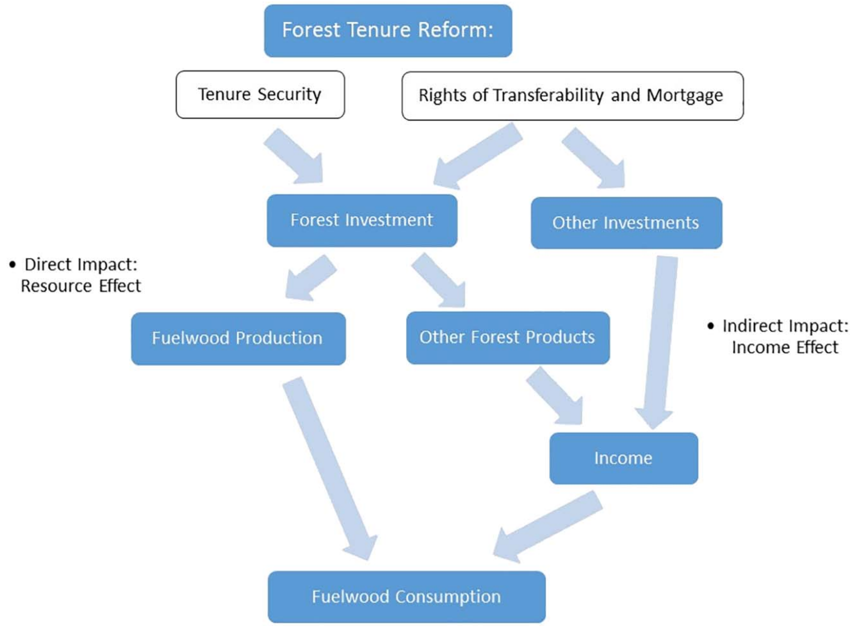

Fig. 1. Conceptual framework: The mechanisms through which the forest tenure reform can affect household fuelwood consumption.

4. Empirical strategy

4.1. Conceptual framework

Our interest is the household responses to the reforms in China's collective forest tenures in terms of energy consumption. Forests devolved to households with secure tenure rights are expected to receive increased investment in forests, and following the investment, increased production (Holden, Yi, et al., 2013; Yi et al., 2014). The increase in production might be consumed in the household of the tenure holder, and other products of the new investment might be exchanged in local markets, with the producer households receiving income from the sales. The market exchange creates additional wealth, some of which the households may use to purchase additional energy, either fuelwood or its substitutes. Therefore, secure and clearly defined tenure could have impacts on both production and consumption.

An important concern is the possibility that households may lose their access to the (common) forests where they previously collected fuelwood, if the villages distribute collective forests to private users.[4] Indeed, due to labor time and the individual's capacity to carry the wood (Robinson, Albers, & Williams, 2008), fuelwood is usually collected in forests close to household homesteads. However, if the devolved forestland is secured as a household's own fuelwood source, the household will not necessarily suffer from the loss of a nearby forest that used to be its source of fuelwood. In that respect, tenure reform can improve households' welfare. Yi et al. (2014) find that, after the devolution reform, the average distance of the household-managed forest plots to their homes is 2 km, in a study of a number of provinces. In Yunnan province, this distance is on average 3 km. These are both short distances, implying that, the forest tenure reform improves their welfare by shortening the distance or securing the source(s) to collect fuelwood from their own plots. Compared to common property, when households have more secure and clear tenure rights in more forest land, forest investment increases, forestation increases, and costs to collect fuelwood decrease (Xie et al., 2016; Yi et al., 2014).

Fig. 1 shows a conceptual framework for the mechanisms through which forest tenure reform is expected to affect fuelwood demand.[5] Conceptually, forest tenure reform could affect fuelwood consumption and demand through the following direct and indirect channels.

First, through tenure security, household-managed forestland receives better management and increased investment, which in turn increases forest production so as to increase the availability of fuelwood. This channel is formulated as the direct impact of forest rights devolution on fuelwood consumption through an increase in available wood for fuel. We call it the "resource effect."

Second, there is also an indirect impact of forest rights devolution on fuelwood consumption, through the income effect. On the one hand, regardless of where households collect their fuelwood, the households' own forests produce forest products such as timber and fuelwood, and non-wood forest products (NWFP): forage and fodder for livestock, fruits and nuts, mushrooms and herbs, etc. These NWFP are particularly important in Yunnan. For households who can collect fuelwood from other lands, these other products (not fuelwood) may be the more important products of their own, independently managed forests, either for their own consumption or for market exchange. These income-generating activities raise household income, so that could increase their fuelwood demand

[4] We thank one of our reviewers for pointing out this interesting issue for discussion.
[5] We thank one of our reviewers for the advice.

(Baland et al., 2010; Zhang & Kotani, 2012). In addition, the most important improvements from the new round of forest tenure reform include the issuance of a certificate for the household's forest land. The certificates can be used to transfer and as collateral when obtaining loans. Therefore, the certificates improve household access to borrowing and to new investment opportunities, some of which may be outside of forestry. Some households with forest certificates may have taken advantage of the non-forest investment opportunity these certificates can create and, therefore, added another source of household wealth – and another impact on household demand for fuelwood or its substitutes.

Through these two channels, tenure reform can affect household fuelwood consumption. Our empirical analysis focuses on the identification of the direct impact on fuelwood consumption through the resource effect. Household income is controlled for as a household characteristic.

4.2. Econometric strategy

Based on the above conceptual framework, to identify the direct impact of forest rights devolution on fuelwood consumption, we propose an analytical framework to assess fuelwood demand and supply simultaneously. The available data, however, limit our ability to examine fuelwood supply. Therefore, following Chen et al. (2006), Demurger and Fournier (2011), Heltberg et al. (2000), Lee (2013) and Zhang and Kotani (2012), our attention focuses on the generalized household demand for fuelwood in a framework of a non-separable household model, defined in Eq. (1):

$$Q_d = Q_d\left(p_f, \mathrm{p_s}, I; \boldsymbol{\Omega}, FTR\right) \tag{1}$$

where Q_d is the quantity of fuelwood demanded, p_f is the fuelwood price, $\mathrm{p_s}$ is a vector of prices of the substitutes energy sources, I is household income or wealth, and Ω is a vector of household and local demographic characteristics affecting fuelwood consumption. *FTR* represents forest tenure reform, measured by the percentage of forestland in a village that has been devolved to households. *FTR* is the crucial independent variable to answer our question: whether an increase in forest rights devolution leads to an increase in household fuelwood consumption.

Fuelwood markets are thin, but they do exist and price information is available for most of the villages in our sample. While only a few households participate in these markets, others could – and they would if prices rose, thereby encouraging more production for market sale, or if prices fell, thereby encouraging some households to convert from collecting for themselves to purchasing in the market.

To estimate Eq. (1), we establish the reduced form econometric model as follows.

$$Q_{ij} = \alpha + \beta_1 p_{f,\mathrm{j}} + \beta_2 \mathrm{p_{s,j}} + \beta_3 I_{\mathrm{ij}} + \beta_4 \boldsymbol{\Omega}_{\mathrm{ij}} + \beta_5 FTR_{ij} + \varepsilon_{ij} \tag{2}$$

The subscripts *i* and *j* refer to households and villages, respectively. The dependent variable for the demand equation is the sum of fuelwood produced from own plots plus fuelwood purchased in the market. In addition, Eq. (2) is estimated separately for fuelwood collected from own plots, and for fuelwood purchased from local markets. The β vector contains coefficients to be estimated and ε is a random error term.

We estimate Eq. (2) in the logarithmic forms of the dependent variables and the main explanatory variables, where possible. Therefore, most of the coefficients are elasticities. This function satisfies our two primary objectives: to trace the effect of tenure reform on fuelwood consumption and to examine the substitution effects between alternate sources of energy.

The estimation of Eq. (2) using the Ordinary Least Squares (OLS) produces consistent parameter estimates only when the assumption on exogeneity is satisfied, i.e., $E(\varepsilon \mid FTR, \boldsymbol{\Omega}, I, \mathrm{p}) = 0$. However, only a subsample of households (375 of 533 households in the final sample) use fuelwood. Therefore, the OLS estimates could be inconsistent due to the sample selection bias – if $\varepsilon_{ij} = \boldsymbol{\Gamma_{ij}}\theta_{\mathrm{ij}} + \in_{ij}$, where $\boldsymbol{\Gamma_{ij}} = \left(FTR_{ij}, \boldsymbol{\Omega}_{\mathrm{ij}}, I_{ij}, \mathrm{p_j}\right)$. To correct for the bias, we use the Heckit method developed by Heckman (1979). We estimate $\boldsymbol{\Gamma_{ij}} = \left(FTR_{ij}, \boldsymbol{\Omega}_{\mathrm{ij}}, I_{ij}, \mathrm{p_j}\right)$ as a first-stage selection model, by a probit regression on the likelihood of positive fuelwood consumption. The inverse Mills ratio $\left(\lambda(\boldsymbol{\Gamma_{ij}}\widehat{\theta}_{\mathrm{ij}}) = \frac{\phi(\boldsymbol{\Gamma_{ij}}\widehat{\theta}_{\mathrm{ij}})}{\Phi(\boldsymbol{\Gamma_{ij}}\widehat{\theta}_{\mathrm{ij}})}\right)$, calculated from the selection model, is calculated for each household and controlled for as an additional factor in the estimation of Eq. (2) as a second stage. The estimated parameter of the inverse Mills ratio measures the covariance between the two residuals ε_{ij} and $\in_{ij}$, and a conventional *t*-test indicates whether the sample selection results in significant bias.[6]

FTR_{ij} and I_{ij} are included in both the selection model and the outcome model, because the resource effect may drive a household using fuelwood as well as the amount of use, given a certain (mean) level of income. Household income (wealth) is a crucial variable that determines household energy consumption, but empirical findings about the direction of its impact on fuelwood consumption are inconclusive; they are differentiated by assuming fuelwood as a normal good or inferior good (Chen et al., 2006; Demurger & Fournier, 2011; Zhang & Kotani, 2012). By controlling for household total income, the estimated coefficients of the tenure variable only show the direct effects (e.g., through investments and improved forest management) at given household income levels.[7] $\boldsymbol{p_j}$ is included in both models to account for both the own-price effects and the substitutive effect of alternative sources (i.e., charcoal, coal,

[6] If the null hypothesis of $H_0 : \gamma_1 = 0$ cannot be rejected, it implies that the OLS estimates using the selected sample (of all positive consumption in our case) are unbiased and consistent, and vice versa (Heckman, 1979; Wooldridge, 2010).

[7] We acknowledge the comment by one of our reviewers. The model can be extended by adding an equation that specifies the impact of forest rights devolution on household incomes, and then estimating the indirect effects. But such an extension may be beyond the scope of the current paper.

electricity and LPG) (Gupta & Köhlin, 2006; Couture, Garcia, & Reynaud, 2012; Zhang & Kotani, 2012; Lee, 2013).

In $\boldsymbol{\Omega}_{ij}$, we include the following variables in the selection model: household head's age, education and ethnic status, since household heads are the main decision makers in rural areas; household size, as larger households need to consume more food and thus more energy for cooking (Chen et al., 2006; Demurger & Fournier, 2011; Jiang & O'Neill, 2004), and its squared term, because there may be scale economies, where the increase in demand for energy is at a decreasing rate (Zhang & Kotani, 2012); the ratio of off-farm income to agricultural income, with a higher ratio implying that more household members work outside,[8] but the income effect could increase household fuelwood consumption, as discussed above (Shi et al., 2009); and farmland size, as larger area of farmland can bring higher crop income while causing household members to eat meals at home (rather than working in a town), resulting in greater demand for energy for cooking and heating (Chen et al., 2006). Household's ethnic status is included in the selection model but not in the second-stage outcome model, because it is found more likely to affect a household's fuel choice but not the amount of fuelwood consumption (Gupta & Köhlin, 2006).

Standard errors are clustered at village level, because of the distribution of household samples with a clustering trait on villages. Adjusting the default standard errors corrects the regression model errors when the covariates are correlated within villages, though independent across the villages (Cameron & Miller, 2015; Rogers, 1993).

5. Data

5.1. Survey area

Yunnan is a mountainous province in China's inland southwest. It is poor, and well forested with a large forest area per capita. Its inhabitants include many ethnic minorities. These tend to be traditional and less rapid adopters of various things new, including new forest policy. They tend to follow their own strong leaders who, in the case of the forest reforms, have often preferred to maintain their own control of the village's collective forests rather than participate extensively in the reforms that would transfer more lands to individual households. Yunnan was one of the later provinces to issue a provincial decree authorizing the transfer of collective forest management to independent households. Therefore, it's not surprising that only 53% of the collective forests in Yunnan villages in our sample had been transferred to individual contracts by 2010.

Yunnan is a good candidate for our examination of the effect of the new round forest tenure reform on the consumption of fuelwood, due to the following characteristics: large forests, low per capita household incomes and therefore a strong dependence on fuelwood, later provincial authorization of the most recent forest reforms, and hesitant local adoption of those reforms.

5.2. Data

The data used for this paper come from a household survey conducted by Peking University in 2011. The survey was designed to evaluate the impact of Collective Forest Tenure Reform on household livelihood, forest management, land transfers, etc. The investigated households were selected based on the principle of stratified random sampling. In particular, the survey covered six counties, where two townships per county and two to three villages per township were randomly selected with adjustments to allow for geographic dispersion. Fig. 2 depicts the distribution of surveyed villages.

Twenty households were randomly selected from the official registers of each village council. The households were interviewed face to face about their household and individual demographic characteristics, agricultural and forestry production activities, a variety of income sources and fixed assets, fuelwood and other energy consumption, etc. The original sample size was 575. Eliminating the households with missing information yields a sample size of 533. Among the 533 households, 375 households have positive fuelwood consumption.

Table 1 summarizes our data. The majority of fuelwood consumption was self-produced, i.e., from their own forest plots. Nevertheless, households in our survey purchased a substantial 21.4% of their consumption from the market, and this alone is evidence that an active fuelwood market does exist. However, none of our households reported selling in the market—and this leaves us with a question about potential bias in our eventual estimated results. Hyde and Köhlin (2000) observed that this anomaly is common throughout the fuelwood literature. Surveyed households often reported purchases but generally did not report fuelwood sales. Of course, markets can only exist in the presence of both sales and purchases. What caused previous household surveys to uniformly overlook selling households? Did the surveys fail to ask a question about market sales? We might anticipate that selling households were poorer households – in which case their absence does create an important distributive bias.

In fact, 53 households (14% of the entire sample) in 22 of 30 villages reported fuelwood prices, all in the range of 0.1–3.0 CNY per kg.[9] Where multiple households in a village reported market prices, we use the average for these households as the village price in our empirical analysis. For the eight villages for which we do not have an observation on price, we use the price from the nearest neighboring village. Village average fuelwood prices fall in the range 0.2–1.7 CNY per kg, a broad range that is convenient for

[8] Household demands on cooking and heating could decline when some members are away from home.

[9] The number of households reporting a local market price for charcoal, LPG, coal and electricity is 74, 23, 31 and 477 respectively.

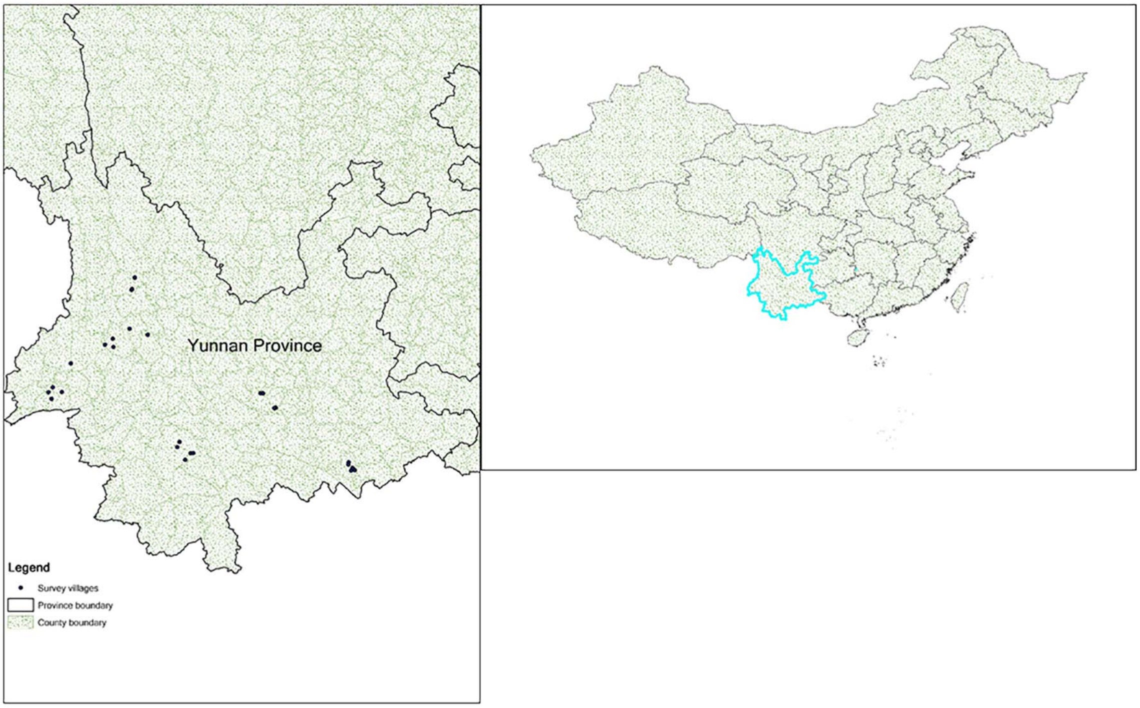

Fig. 2. Distribution of surveyed villages in Yunnan.

Table 1
Summary statistics: households in Yunnan Province, 2010 annual data.

Variable	Obs.	Mean	Std. dev.	Min	Max
Household characteristics					
Fuelwood consumed by household, self-produced, in kg	375	1543.795	2340.439	0	25,000
Fuelwood consumed by household, market purchased, in kg	375	298.523	1010.588	0	8000
Total household income in CNY	533	45,976.05	40,470.73	1575.4	286,540
Off-farm to total household income ratio	533	0.318	0.314	0	0.986
Total number of household members, persons	533	4.261	1.697	1	11
Number of household members engaged in off-farm employment, persons	533	3.141	1.295	0	8
Number of household adults between 16 and 55 (female) or 60 (male) years old, persons	533	2.625	1.174	0	6
Age of household head, years	533	48.852	11.313	20	85
Household head education, years	533	5.475	3.164	0	14
Ethnic minority status of household head, 1 = yes, 0 = no	533	0.664	0.473	0	1
Household total agricultural land area, mu[b]	533	7.208	6.831	0	67
Household income share from forestry	533	0.108	0.188	0	0.964
Distance to fuelwood gathering point in km	533	3.012	1.712	0.500	7.679
Distance to county center in km	533	40.398	24.358	0	83
Village characteristics					
Average village fuelwood price per kg	30	0.650	0.398	0.199	1.783
Average village charcoal price per kg[a]	30	3.481	3.670	1.500	21.797
Average village LPG price per kg[a]	30	7.185	1.513	4.853	12.143
Average village coal price per kg[a]	30	0.997	0.808	0.500	3.340
Average village electricity price per kwh[a]	30	0.528	0.084	0.452	0.825
Village forest area per capita in ha	30	0.765	0.753	0.070	3.735
Forest to arable land ratio for the village	30	1.208	2.042	0.056	8.818
The extent of forest devolution: household-managed forests as a percentage of the village's total forest area	30	0.533	0.370	0	1

Note: There are 375 households with a positive amount of fuelwood consumption, while the remaining 158 households do not consume fuelwood. Household total income is aggregated from the household's agricultural sales (including livestock), off-farm work income, forestry income, other asset income, and governmental transfers. Consumption of own-produced fuelwood is not included in income.

[a] The quality of the price data for the alternative energy sources may be low, because they are average village price data based on a small number of households, due to limited data availability. We regard these prices as local market prices so that the price of each good does not vary a lot in each village. In particular, the retail markets for coal and charcoal are competitive, as it is hard to differentiate the good by different suppliers. LPG and electricity prices are set by the government, so locally the prices are similar for each good among households.

[b] Mu is a land area unit used in rural China, with 1 mu equal to 1/15 hectare.

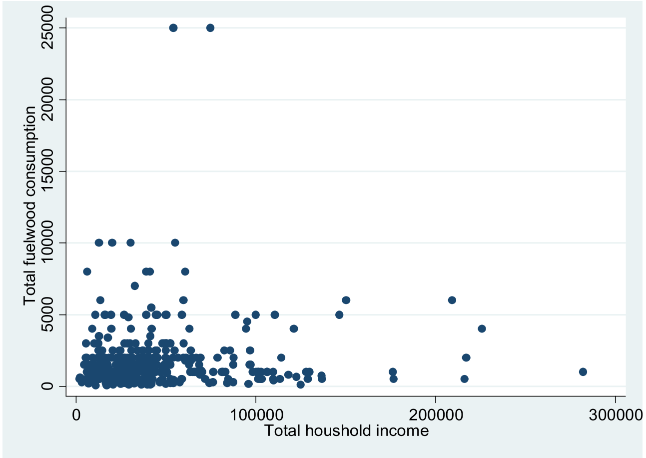

Fig. 3. Household fuelwood consumption (kg per year) by total income level (CNY per year).

statistical analysis. The prices of substitutes such as charcoal, LPG, coal, and electricity are village averages of prices reported by households in each village.[10]

On the extent of forest rights devolution, we observe that the average village in our sample had transferred only 53.3% of its collective forests to individual household management by 2010. As earlier discussed, the central government has approved tenure reform until as much as 90% of village forest is no longer managed by the collective. But very few villages in Yunnan have already gone beyond this and transferred 100% of their forests from collective to individual management.

Among household characteristics, we can see that the off-farm income on average accounts for 32% of the total household income, while the forestry income is only 10.8%.[11] Fig. 3 shows the scatter plot of fuelwood consumption by household income. Clearly, the majority of households are clustered in a large group of low income (receiving 60,000 CNY or less). Excluding the two outliers, households in this cluster consume no > 5000 kg of fuelwood annually. The group of households with higher annual income shows a declining trend in the number of households entering the group as income increases. Despite this, we do not observe the distinct drop in fuelwood consumption for the higher income group.

The average household size is 4.261, of which 2.625 are adult labor and 3.141 engaged in off-farm employment. The household heads are on average < 50 years old, with primary school education. Further, 66% of the households are from an ethnic minority group. With regard to village characteristics, we can see that the village forestland area per capita is 0.762 ha. The average distance from the village to the closest county center is > 40 km, which indicates that the sampled villages are quite remote.

6. Results

6.1. Estimation results

The main econometric results are presented in Tables 2 and 3, using the Heckit approach in estimating Eq. (3). Table 2 reports the first-stage result, i.e., the selection model, by a probit regression on the likelihood of a household consuming any fuelwood. As expected, the likelihood of positive fuelwood consumption significantly decreases with the fuelwood's own price. This is consistent with Gupta and Köhlin (2006) and Couture et al. (2012). In particular, a 10% increase in fuelwood price will decrease the likelihood of using fuelwood by 4.95%. For the alternative energy substitutes, only the price of charcoal has produced a significant and negative effect on the likelihood of fuelwood choice. The substitution effect is not large; specifically, a 10% increase in charcoal price will increase the likelihood of fuelwood use by 6.92%. We do not find that any of the other household characteristics, including household income and ethnic status, has significant impact on the likelihood of fuelwood choice. This could imply that fuelwood is a normal good in our sample areas. As expected, we find that forest rights devolution significantly increases the likelihood of fuelwood consumption. A 10 percentage point increase in village forestland under household management increases the likelihood of fuelwood use by 7.66%.

In Column 2, we add forestry income share and its interaction with the tenure variable, in order to control for the short-run contribution of the forest devolution reform to forestry income, which increases the forestry share of total income.[12] Forestry income

[10] The quality of the price data for the alternative energy sources may be low, because they are average village price data based on a small number of households (due to data availability). We regard these prices as local market prices so that the price of each good does not vary a lot in each village. In particular, the retail markets for coal and charcoal are competitive, as it is hard to differentiate the good by different suppliers. LPG and electricity prices are set by the government, so locally the prices are similar for each good.

[11] Forestry income does not include consumption of own-produced fuelwood.

[12] We believe that this contribution occurs due to strengthened forest use rights, which permit harvest of non-wood forest products, for example. After controlling for the forestry income share and its interaction term with the tenure variable, the coefficient of the tenure variable is interpreted as the partial effect of forest rights devolution on fuelwood consumption at the mean percentage level of income coming from forestry.

Table 2
Results of the selection equation: factors correlated with positive fuelwood consumption.

Dependent variable: household fuelwood consumption if positive	(1)	(2)
	Probit	
Log of fuelwood price	− 0.495***	− 0.498***
	(0.122)	(0.123)
Log of charcoal price	0.692***	0.724***
	(0.220)	(0.228)
Log of coal price	0.210	0.242
	(0.168)	(0.174)
Log of electricity price	0.781	0.765
	(0.660)	(0.682)
Log of LPG price	0.352	0.445
	(0.431)	(0.440)
Log of household size	− 0.347	− 0.295
	(0.645)	(0.677)
Log of household size squared	0.200	0.183
	(0.246)	(0.258)
Age of household head	0.005	0.006
	(0.006)	(0.006)
Education years of household head	− 0.031	− 0.028
	(0.022)	(0.022)
Ethnic minority status of household head	0.074	0.040
	(0.152)	(0.155)
Log of household income	0.562	0.635
	(1.218)	(1.253)
Log of household income squared	− 0.030	− 0.037
	(0.059)	(0.061)
Off-farm income ratio	− 0.389	− 0.161
	(0.260)	(0.282)
Log of agricultural land area	0.119	0.145
	(0.098)	(0.102)
The extent of forest rights devolution	0.766***	0.832***
	(0.242)	(0.262)
Forestry income share		3.957***
		(1.495)
Forestry income share ∗ tenure		− 3.732**
		(1.837)
Constant	− 3.642	− 4.201
	(6.266)	(6.442)
Pseudo R2	0.183	0.200
Observations	533	533

Note: Robust standard errors in parentheses. Significance is denoted: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

share is found to have a positive effect on the likelihood of a household consuming fuelwood. Furthermore, considering a certain level of household income and its income from forestry constant, the devolution of forest rights would have a larger direct impact on the increase in the likelihood of consuming fuelwood, specifically, 0.832 versus 0.766.

Table 3 provides the results of the second-stage model on the amount of fuelwood consumption by OLS. The dependent variable is the natural log of the amount of household fuelwood consumption.[13] The first two columns of Table 3 are results of the full sample on total household fuelwood use. The parameter estimates of the inverse Mills ratio are significant at the 10% level, suggesting the sample selectivity would bias the OLS estimates if only the selected sample were regressed. Again, in Column 2, we add the forestry income share and its interaction with the extent of forest rights devolution. Column 3 and 4 distinguish the effects of prices and of the tenure reform between self-produced fuelwood and fuelwood bought through the market.[14]

The main results on the impact of the tenure reform provide empirical support for the hypothesized relationship between tenure rights devolution and fuelwood consumption. We find the coefficient on our tenure measure, i.e., the percentage of forest devolved to household management, is significant in most models, at 0.699 in Column (1), for example, confirming the prior suggestion that tenure reform has an important direct and positive effect on household fuelwood consumption. A 10 percentage point greater amount of forestland in the village given to household management caused a 6.99% shift in total fuelwood consumption by the average household. The same change in tenure is estimated to increase the fuelwood consumption from own-plots by about 14.53%

[13] An aside on supply: The dependent variable for household fuelwood supply—if we had the data—would include a measure of the production that each household supplies to the market summed with the same measure of household production for self-consumption. The absence of observations on the former prevents any attempt to estimate supply.

[14] We thank one of our reviewers for pointing out that the effects of the tenure reform and fundamental prices on consumption from own plots and from market purchases are distinguishable.

Table 3
Results on household fuelwood demand: the Heckit approach.

Dependent variable: log of fuelwood consumption	(1)	(2)	(3)	(4)
	Heckit approach		From own plots	Purchased
Log of fuelwood price	− 0.255***	− 0.227***	− 0.147	− 1.969***
	(0.094)	(0.086)	(0.533)	(0.301)
Log of charcoal price	0.148*	0.145*	0.229**	0.563
	(0.085)	(0.085)	(0.103)	(0.470)
Log of coal price	0.033	− 0.004	− 0.103	0.279
	(0.109)	(0.099)	(0.149)	(0.430)
Log of electricity price	0.421	0.398	1.202***	0.163
	(0.526)	(0.492)	(0.456)	(0.195)
Log of LPG price	− 0.347	− 0.315	− 0.219	− 0.285
	(0.271)	(0.279)	(0.383)	(0.868)
Log of household size	0.974**	1.016**	0.837*	0.763
	(0.448)	(0.509)	(0.504)	(0.933)
Log of household size squared	− 0.321**	− 0.336*	− 0.179	− 0.350
	(0.158)	(0.182)	(0.177)	(0.286)
Age of household head	0.002	0.002	− 0.005	0.013
	(0.003)	(0.003)	(0.005)	(0.021)
Education years of household head	− 0.015	− 0.012	− 0.014	− 0.008
	(0.010)	(0.009)	(0.020)	(0.063)
Log of household income	1.159***	1.175***	1.116***	0.929**
	(0.151)	(0.157)	(0.255)	(0.388)
Log of household income squared	− 0.053***	− 0.057***	− 0.053***	− 0.027
	(0.009)	(0.009)	(0.014)	(0.021)
Off-farm income ratio	− 0.359	− 0.112	− 0.357	− 0.668
	(0.220)	(0.248)	(0.259)	(0.614)
Log of agricultural land area	0.153	0.187*	0.268**	− 0.310
	(0.097)	(0.096)	(0.135)	(0.293)
The extent of forest devolution	0.699***	0.547***	1.453***	− 0.004
	(0.165)	(0.154)	(0.442)	(0.274)
Forestry income share		0.384		
		(0.392)		
Forestry income share ∗ tenure		0.468		
		(0.569)		
Inverse Mills ratio	0.278*	0.214	0.327	0.0866
	(0.147)	(0.135)	(0.416)	(0.231)
Observations	533	533	533	533
Number of censored observations	158	158	303	460
Log Pseudolikelihood	− 746	− 737.5	− 579.3	− 326.8

Notes: Standard errors in parentheses are clustered at the village level. * Significant at 10%; ** significant at 5%; *** significant at 1%. Columns 1 and 2 report the results for the full sample. Columns 3 and 4 report the results for fuelwood consumption demand from own forest plots and fuelwood purchased from local market, respectively.

(Column 3), with no significant effect on the amount of fuelwood purchased from the market (Column 4). It indicates that the positive impact of forest rights devolution on fuelwood consumption is mainly through the increase in households' access to forestland. In fact, the impact may have been large, as our survey data indicates that a 30% increase in the forest area had been reallocated to households during the period, implying that the fuelwood consumption will be increased by over 20%.

It is clear that the extent of forest rights devolution is a significant determinant of the household fuelwood consumption. Its large impact is strongly suggestive that forest production must have increased during the period of tenure reform and, therefore, that tenure reform must have been an inducement for additional forest management. In fact, the forest area in the 30 villages of our survey increased by 27%, from 37.5 mu to 47.8 mu per household, in the short period of five years between 2005 and 2010. Controlling for total household income, this impact is regarded as the direct effect through increased forest production (e.g., through investments and improved forest management), as discussed earlier in the conceptual framework. However, there may exist an additional channel as an indirect impact of forest tenure reform on fuelwood consumption when a household's income share from forestry increases (i.e., forest and non-forest products incomes). Including the forestry income share and the interaction term between this share and the tenure variable supports this hypothesis. Given the continuous variables of forestry share and tenure reform, the coefficient of the tenure measure in Column (2) is interpreted as the partial effect of forest rights devolution on fuelwood consumption at the mean level of forestry income share, which decreases to 0.547.

The fuelwood price has the expected sign and the elasticities are statistically significant. This is consistent with other empirical assessments on fuelwood demand (Amacher et al., 1996; Baland et al., 2010; Heltberg et al., 2000; Jumbe & Angelsen, 2011). The significant small and negative coefficient on fuelwood price indicates that households decrease their fuelwood consumption as the price increases. A 10% increase in price induces a 2.55% decrease in total fuelwood consumption, and decreases the amount purchased from markets by almost 20%, while such effect is insignificant for fuelwood collected from own plots. These results are consistent with the expectation that the purchased fuelwood is much more sensitive to the market prices than is the fuelwood collected from own plots.

We next examine four fuelwood substitutes: charcoal, coal, electricity and LPG. The substitute prices have the expected signs, in particular in the distinguished models (Columns 3 and 4), though the mostly insignificant results suggest they have zero impact. Charcoal is a significant substitute for fuelwood. In the case of a 10% increase in the charcoal price, households switch their fuel consumption pattern, with a 1.48% increase in fuelwood use. Consistent with Zhang and Kotani (2012), none of the other three is a statistically significant substitute, except that an electricity price increase is found to significantly induce households to consume more fuelwood from own plots. This indicates that households mainly depend on the fuelwood collected from their own plots. Coal and LPG may be too expensive at prices observed for 2010 or they may simply be less available, especially for more remote villages and households. Plots of fuelwood consumption indicate a decline almost to zero in consumption by households beyond approximately 8 km from the nearest larger town.[15]

Although we do not find significant impacts of household income on the likelihood of fuelwood use, it is found to have nonlinear positive effects on the amount of fuelwood demand. Together with the positive coefficient of the logarithm of income and the negative coefficient of its squared term, fuelwood consumption is a positive but declining portion of increasing total income – as expected. Specifically, households start to reduce their fuelwood consumption when their income reaches CNY 56,047. Even at that higher income level, fuelwood remains a necessity for most Yunnan households, which shows that the "energy ladder" hypothesis does not completely hold in all circumstances. The results corroborate Baland et al. (2010)'s findings, while contradicting Demurger and Fournier (2011) and Chen et al. (2006). For off-farm income, we do not find any significant effect on fuelwood consumption. This is consistent with Shi et al. (2009), who found that increased off-farm employment may not necessarily promote the energy transition in poorer rural China.

The size of the household (number of household members) is a common variable in the fuelwood literature. We find that household size has a nonlinear positive effect on fuelwood demand (in Columns 1 and 2), in which the effect starts to decrease fuelwood consumption when household size increases to 4.559. This confirms the previous evidence on the significant role of household size in determining household energy demand (Demurger & Fournier, 2011; Jiang & O'Neill, 2004; Zhang & Kotani, 2012). Stated otherwise, the negative coefficient of the squared term of household size implies substantial scale economies in household fuelwood consumption. We do not find any other household characteristics, such as household head's age and education or ethnic status, that significantly affect household fuelwood consumption.

Finally, in a separate regression, we introduced dummy variables to distinguish five counties from a baseline sixth county in the Yunnan sample. None of the five coefficients was statistically different from the first. Since Yunnan's ethnic groups tend to live each in their own local communities, this absence of county distinction suggests that there is little difference in consumption by ethnic group. Distance to the county center, another way to capture local differences, was also insignificant, although the sign on this final independent variable was negative, perhaps suggesting that smaller distance to the larger town also meant better access to local markets and, therefore, to commercial fuelwood substitutes.[16]

6.2. Robustness checks and further assessment of the impact of forest tenure

We report in Table 4 the results of robustness checks of our main findings.[17] Firstly, column 1 shows whether the Heckit estimates (of Column 1 in Table 3) are sensitive to the two outliers of households with low income but extremely high fuelwood consumption. The new regression, dropping the two outliers, does not affect the Heckit estimates in a significant different way, except for no significant effect of charcoal as a substitute.

Two additional columns (2 and 3) in Table 4 perform the sub-group analysis for two income groups of equal size, distinguished by the county-median income. Because fuelwood is a household necessity, it will be of greater relative importance for lower income households as they consider their allocation of expenditures across all goods and services. The new regressions will display the change in consumption behavior as incomes progress from lower to higher income clusters. Of particular interest to us, the tenure reform in the new regressions will show the relative annual benefit that the different income groups obtained from more secure forest tenure at the time of our sample.

The coefficients on the tenure term are the most interesting result. They are statistically significant and positive in all the models of both Tables 3 and 4. They confirm that the devolution of forest rights is a significant determinant of the level of fuelwood consumption for both income groups. The coefficient is greater for the lower income group (0.790 versus 0.582), suggesting a bigger welfare improvement for the lower income population. Therefore, households in Yunnan benefitted in the form of additional fuelwood consumed as a result of the new round of tenure reform and the lower income households benefitted more.

A 10 percentage point increase in the individually managed share of a village's collective forests increased fuelwood consumption by 7.9% for lower income households. A larger 30% increase, as was the general experience in Yunnan over the period of the new round of forest tenure reforms from 2000 until 2010, was associated with a 23.7% increase in the fuelwood consumption of the lower income households. This is a substantial benefit because of the tenure reform, and it is especially important in the context of the central government's desire that the reform would have a beneficial impact on poorer communities. The impact on lower income

[15] The plots figure is not shown here, and is available upon request to the corresponding author.
[16] These regressions are also not shown. They too are available from the authors.
[17] We thank the editor and our reviewers for their advice on robustness checks.

Table 4
Robustness: sensitivity to outliers and by income levels.

Dependent variable: log of fuelwood consumption	(1)	(2)	(3)
	No outliers	Lower income	Higher income
Log of fuelwood price	− 0.226***	− 0.144	− 0.410**
	(0.081)	(0.103)	(0.162)
Log of charcoal price	0.129	0.035	0.285**
	(0.082)	(0.145)	(0.140)
Log of coal price	0.023	0.119	− 0.147
	(0.097)	(0.140)	(0.166)
Log of electricity price	0.519	− 0.151	1.210***
	(0.481)	(0.741)	(0.463)
Log of LPG price	− 0.373	0.002	− 0.972*
	(0.272)	(0.595)	(0.589)
Log of household size	0.980**	− 0.191	2.497***
	(0.448)	(0.616)	(0.494)
Log of household size squared	− 0.332**	0.132	− 0.844***
	(0.162)	(0.256)	(0.177)
Age of household head	0.001	0.003	− 0.003
	(0.003)	(0.004)	(0.008)
Education years of household head	− 0.011	− 0.006	0.002
	(0.009)	(0.019)	(0.025)
Ethnic minority status of household head	0.026	0.032	− 0.051
	(0.114)	(0.123)	(0.149)
Log of household income	1.220***	1.111***	1.197***
	(0.143)	(0.282)	(0.306)
Log of household income squared	− 0.057***	− 0.051**	− 0.051***
	(0.009)	(0.020)	(0.019)
Off-farm income ratio	− 0.310	− 0.005	− 0.621**
	(0.221)	(0.269)	(0.300)
Log of agricultural land area	0.123	0.109	0.184
	(0.090)	(0.109)	(0.127)
The extent of forest devolution	0.679***	0.790**	0.582**
	(0.157)	(0.315)	(0.282)
Inverse Mills ratio	0.210**	0.162	0.31
	(0.095)	(0.234)	(0.227)
Observations	531	268	265
Log Pseudolikelihood	− 739	− 366.1	− 362.1

Notes: Standard errors in parentheses are clustered at the village level. * Significant at 10%; ** significant at 5%; *** significant at 1%.

households is relatively higher than the 20% increase experienced by higher income households over the same 10-year period – an increase that is notable when we consider the prior evidence that these higher income households have a lower preference for additional fuelwood.

Fuelwood consumption in the higher income group is more responsive to changes in its own price, while the response to price change in lower income households is not statistically significant. The price elasticity of − 0.410 of higher income households seems to drive the overall and average effect on fuelwood demand. The higher income households are also found to substitute fuelwood for charcoal and electricity as the prices of those products rise. The possible explanation could be that they are likely to be more sensitive to the price changes in substitute fuels. On the one hand, the small coefficients confirm our previous findings that fuelwood is a necessity. On the other hand, the result suggests that the higher income households are more likely to adopt modern fuels (as we find in electricity) at the expense of fuelwood consumption. This result is consistent with previous literature showing that electricity consumption is positively correlated with household income and living standard (Chen, Kuo, & Chen, 2007; Joyeux & Ripple, 2007; Shiu & Lam, 2004).

In addition, we find the significant and negative effect of off-farm income on fuelwood demand only for higher income households. This indicates that it is more difficult for lower income households to escape dependence on the fuelwood. In contrast to higher income households, there is no significant effect of household size on fuelwood demand for lower income households. This finding further validates that lower income households have higher dependence than high income households on fuelwood. The reasonable explanation is that, for lower income households, the first allocation of fuel for cooking and heating is absolutely necessary, but neither adding to the number of family members in the household not subtracting for family members employed away from home significantly affects the quantity of fuel necessary for either cooking or heating.

7. Conclusion

Widespread devolution of rights in forest management should, in one place or another, increase all the products of the forest. Fuelwood is the most widely used of these products. It is an important consumer good for most rural households, but especially for poorer households. Its widespread consumption, along with the income distributive objectives of China's tenure reforms, make fuelwood a good choice for an assessment of the chain of effects from forest rights devolution to forest production to rural household consumption.

With this justification, we examined household fuelwood consumption – or demand – as a function of its usual determinants: price, prices of substitutes of energy sources, household income, and specialized local and demographic characteristics, plus the policy variable, the extent of forest rights devolution. Tenure has not been a component of previous estimates of fuelwood demand –but fuelwood, in those mostly African and South Asian cases, has been largely a product of unmanaged open access forests. China's case is different. The rights to China's collective forests are well established. The recent round of forest tenure reform increasingly shifts the management rights to individual households who, with improved incentives, may increase management for all forest production.

We analyzed a household survey dataset of 533 households from 30 villages in six counties in Yunnan in 2010. By 2010, about half of the village-owned forests were managed by households. Our basic regression and two identical regressions, separating the sample population into fuelwood consumed from own plots and purchased from markets, and separating higher and lower income households, verify that fuelwood is a necessity for these Yunnan households. That is, the own price coefficient is negative and small. The effect of household size and income on fuelwood demand is positive and nonlinear. Off-farm employment decreases the demand for fuelwood especially for higher income households.

Our results indicate that lower income households have stronger dependence on fuelwood, and they benefit more from the forest tenure reform. Based on our findings, the potential of further reforms, until 90% of village-owned forests are devolved to households, would be expected to result in a 28% additional increase in fuelwood consumption by the average household in Yunnan. Since this fuelwood is a necessity for our sample households, the increased fuelwood consumption resulting from further forest rights devolution will to a large extent satisfy households' energy demand and thus improve their welfare.[18]

In sum, tenure reform clearly enabled the substitution of an increased volume of fuelwood produced from lands that are either more secure or new to individual management as a result of the reform. This fuelwood substituted for energy from other sources, both from self-produced fuelwood and market purchased energy. Its large share suggests a large increment from the reform forests. Therefore, our findings indicate that the government needs to continue with the devolution process, while the focus should be equally given to the quantity and the quality of forest rights devolution, as is vital for the relatively poorer, resource-dependent rural population.

This paper provides the first investigation of how forest tenure reform affects rural households' fuelwood consumption. However, we need to be cautious in generalizing our findings. As has been discussed, one limitation is that we have limited data on the prices for fuelwood and its substitutes, and another is that we mainly focus on the direct effect of tenure reform on fuelwood consumption (e.g., through investments and improved forest management) given household income levels. Further research is needed to enrich the price information, and explore both the direct and indirect effects (e.g., through the impact of forest rights devolution on household incomes) on fuelwood consumption. In particular, it remains to be seen whether increased household income will eventually result in a greater transition to modern fuels by households in poor regions.

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[18] For these forests to have provided substantial amounts of fuelwood suggests additional investment and management on those forests that became the new responsibility of individual households. Therefore, the forest reforms not only modified household fuelwood consumption, they must have improved the forest environment as well. And, as they did improve the overall forest environment, they must have improved the production and consumption of other forest products and services just as they improved those of fuelwood. In other words, the increase of fuelwood consumption resulted from the forest tenure reform reflects the improved forest management and overall forest environment, and this also will finally improve household incomes and welfare.

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