Migration and Fuel Use in Rural Zambia*

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Abstract

What is the effect of migration on fuel use in rural Zambia? Opportunities to increase income are scarce in this setting; in response, households may pursue a migration strategy to increase resources as well as to mitigate risk. Migrant remittances may make it possible for households to shift from primary reliance on fuelwood to charcoal. The loss of productive labor through migration may reinforce this shift. This paper uses four waves of panel data collected as part of the Child Grant Programme in rural Zambia to examine the connection between migration and the choice of wood or charcoal as cooking fuel and finds evidence for both mechanisms. Importantly, this paper considers migration as a process, including out- as well as return migration, embedding it in the context of household dynamics in rural Zambia.

Keywords: Energy Poverty, Fuel Use, Migration, Household Dynamics, Zambia

JEL codes: Q40, Q56, O15, J10

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Introduction

Migration is an important livelihood strategy in low-and-middle-income countries (LMICs), especially in rural areas (Qin 2010; De Haas 2010). In places where capital, insurance, and credit markets are underdeveloped, rural households diversify against the risks of weather, low crop yields, and price fluctuations inherent in agricultural production by sending one or more household members to another area subject to a different set of risks (Massey et al. 1993; Stark and Bloom 1985; Taylor 1999). Destinations are sometimes international, sometimes not. Remittances from international migrants to LMICs have exceeded $500 million in recent years, three times the amount of overseas development aid and foreign direct investment combined (United Nations 2019). Although national accounts do not track remittances from internal migrants, these flows are undoubtedly significant as well, given that the number of internal migrants is estimated to be four times the number of international migrants (Ratha 2013). But migration does not always result in a benefit to the sending household. Not all migrants remit, and even those who do may not remit much: it depends on their ability to find a job and how well it pays. Whether migrants remit also depends on the strength of their connection to the sending household, which may weaken with time and the accumulation of obligations to new families. Even if migrants remit, their departure results in a loss of productive labor from the sending household (Manning and Taylor 2014; Rozzelle et al. 1999). Whether migration is a net benefit depends on the balance of remittances against the value of the labor lost. As a household strategy, migration is not without risk.

Of interest in this paper is whether migration as a livelihood strategy encourages a transition away from biomass fuel (wood, charcoal, animal dung, agricultural residues) as a household energy source. Nearly half of the world's population today relies on biomass fuel as their primary source of household energy for cooking and heating (IEA 2017). Biomass fuel use varies significantly by region across the world, accounting for more than half of domestic energy sources in developing countries and up to 95% in some of the world's lowest income countries (Ezzati and Kammen 2002). Within these countries, there are often stark urban-rural divides in household energy sources, with rural households disproportionately relying on biomass fuels compared to urban households.

A reduction in the use of biomass fuel could have important health benefits. Exposure to indoor air pollution from the combustion of biomass fuels is a leading cause of mortality in developing countries (Ezzati and Kammen 2002). These pollutants are associated with respiratory infections such as pneumonia, tuberculosis, chronic obstructive pulmonary disease (COPD), lung cancer, and asthma, as well as other health problems such as low birth weight, cataracts, and stroke (Kim et al. 2011). Women and children disproportionately bear the health burdens caused by exposure to biomass smoke, as in most LMICs, women are primarily responsible for cooking for the family (WHO 2018). Further, a reduction in the use of biomass fuels could have environmental benefits. Although evidence suggests that deforestation in rural areas is more likely driven by agricultural growth, residential development, and climate change (Jagger and Kittner 2017; Ribot 1999), fuelwood collection and the production of charcoal (often called a "transition fuel") in more densely populated areas can affect forest environments, especially those proximate to urban areas (Megevand et al. 2013; Zulu and Richardson 2013).

This paper investigates migration and household fuel use in sub-Saharan Africa, where biomass fuel is used more than any other region in the world (Jagger and Shively 2014), and where the majority of rural and poor urban households depend on biomass fuels for their cooking needs

(Makonese et al. 2018). It uses four waves of panel data collected between 2010 and 2017 as part of the impact evaluation of the Child Grant Programme (CGP) in rural Zambia to explore the consequences of migration and other changes in household membership for household fuel use. Households are dynamic, changing in a myriad of ways potentially relevant to labor allocation decisions and choices about fuel use. This paper is the first to compare migration to other changes in household membership and as a related point, the first to consider return migration as well as out-migration. The next section justifies these claims through a discussion of the existing literature on migration and fuel use. We then describe the setting for our study, the data, the measurement of key variables, and the specification of our fixed-effects models. This is followed by a presentation of results. To preview, our results point to the importance of both out- and return migration for fuel use in rural Zambia and to both labor availability and remittances as mechanisms explaining these effects.

Background

As a household livelihood strategy, migration can affect fuel use in two different ways (see **Figure 1**). First, remittances sent back by migrating household members can provide the liquidity that households need to purchase fuels and enable them to consume more expensive, modern energy sources by increasing their income (Manning and Taylor 2014; Taylor et al. 2011; Song et al. 2018; Qin 2010). Remittances are not always sent but may be brought back by returning migrants when they reach their income targets (e.g. Piotrowski and Tong 2010). Second, migration can affect the availability of household labor for agricultural production and fuelwood collection. Households with out-migrants may become more labor-constrained, increasing the opportunity costs of time-consuming fuelwood collection, pushing the household to adopt alternative fuels (Wang et al.

2012; Manning and Taylor 2014; Hou et al. 2017; Gong 2011). Of course, labor lost to migration is potentially restored with the migrants' return. We view migration as a process, embedded in a larger system of interconnections between places of origin and places of destination (Entwisle et al. 2020), and involving movement in both directions, out and return.

The empirical literature addressing migration and household fuel use is relatively sparse. Research on the consequences of migration typically focus on poverty (Christiaensen et al. 2019; Lokshin et al. 2010; Gupta et al. 2009; Rozelle et al. 1999), rarely considering fuel use as a possible outcome. Likewise, research on the determinants of fuel use rarely consider migration (Muller and Yan 2018). Many of the studies of household fuel use that do mention migration deal with the topic indirectly, such as estimating changes in population exposure to household air pollution due to large-scale rural-to-urban migration and associated changes in cooking practices (Aunan and Wang 2014; Ru et al. 2015; Shen et al. 2017; Komatsu et al. 2013), or studying household fuel use in an area where migration is highly prevalent but discussed as context in the study setting rather than examined explicitly as a potential determinant (Hughes-Cromwick 1985; Adelekan and Jerome 2006; Jagger and Shively 2014; Wang et al. 2012). To date, there have been only five studies to examine the effects of household migration on household fuel use directly. We briefly review them here.

We begin with Moran-Taylor and Taylor (2010) and Taylor et al. (2011), who report on a case study of a Mayan community in the Western Highlands of Guatemala where international migration to the U.S. is common. These authors are interested in migrants as potential agents of change in the transition from fuelwood to cleaner fuels. Based on survey data collected from 102 households, they report that migrant households are more likely than non-migrant households to have an LPG stove or an improved woodburning stove and less likely to have a three-stone open fire or cook with wood most of the time. Migrant households are also more likely to purchase fuelwood (94% vs. 88%), suggesting a pattern of fuel stacking rather than transitioning up the energy ladder. These authors also comment on the importance of cultural preferences, which may change as the result of the ideas, behavior, and attitudes migrants bring home with them when they return, i.e., “social remittances”. These two articles are the only ones to include return migration in their discussion of household fuel use, although its effects on fuel use are not specifically assessed.

Qin (2010) focused on the comparison of migrant and non-migrant households in Chongqing Municipality, Southwest China. Based on survey data collected in 345 households in four villages, Qin (2010) found that migrant households were less likely to use fuelwood and crop residue to satisfy their energy needs than non-migrant households (46% vs. 55%). It turned out, however, that differences were concentrated between non-migrant households involved in farming (62%) and non-migrant households that were not (46%). Whether local or distant, off-farm employment was the key to household fuel use in this setting. Migration mattered, but as part of the larger context of decision-making. Because of high levels of out-migration, Chongqing Municipality was characterized by labor scarcity in relation to demand, with plentiful opportunities locally.

Hou et al. (2017) focused their study at the community level. They used data from the China Health and Retirement Longitudinal Survey (CHARLS) to describe correlates of fuel used for cooking in a representative sample countrywide. Although CHARLS is longitudinal, other than describing shifts in fuel use 2008-2012 in Gansu and Zhejiang Provinces, the authors relied on the 2011 wave of data. They examined correlations between the proportion of households using particular fuels (biomass, coal, clean fuels) and urbanicity, socioeconomic development, proximity to market, fuel affordability, education, and one migration variable: the proportion of migrants from the community that is female. Hou et al. (2017) find a positive and significant correlation between this variable and the proportion of households using clean fuels, and a negative but insignificant correlation between it and the proportion of households relying on biomass. Women are the primary fuelwood collectors in most developing countries (Kegode et al. 2017). The number of working-age women in a household may have the greatest effect on the amount of labor available for fuelwood collecting (Link et al. 2012).

Gong's (2011) study moves beyond correlational analysis to specify multiple regression models of fuel use. Based on data from a survey of 1,074 rural households in Qinling Mountains of China, Gong (2011) found a complex interaction between remittances, subjective poverty, and vulnerability such that the expected negative effect of remittances on per capita fuelwood consumption is substantially weakened in subjectively poor and vulnerable households. Gong's (2011) study represents an advance over previous ones in that it controlled for other household and community characteristics that might jointly affect migration and fuel use. However, like previous studies, it relies on cross-sectional data, inferring the effects of migration from differences in energy use between households with and without migrants rather than examining change in fuel use in relation to change in household membership due to migration.

The study by Manning and Taylor (2014) is the only one prior to ours to use longitudinal data. These authors used a formal economic approach to investigate the effects of migration on household fuel use in the context of rural Mexico 2002-2007 when the choice of interest was between collected firewood alone (used by virtually all households) and purchased LPG (which required a special stove). Drawing on two waves of the Mexico National Rural Household Survey, involving approximately 3000 households, Manning and Taylor (2014) showed that households having one or more migrants in the US spent less time collecting firewood, were more likely to have a gas stove, and spent more money on the purchase of gas. Interestingly, the effect of migration depended on migrant destination. Having a migrant somewhere other than the US had no effect on patterns of fuel use, which the authors hypothesize was due to a lower likelihood and lesser average amount of remittances sent.

The Manning-Taylor (2014) study has many strengths, including the use of longitudinal data, careful attention to statistical identification, use of multiple modeling strategies, and tests of robustness. That said, although the authors do demonstrate the effect of migration on time spent collecting firewood—one of the channels through which migration affects fuel use (see Figure 1)—they do not directly address the role of remittances in their analysis. Although they do control for household size, they do not consider migration in relation to household dynamics. Finally, they do not consider the potential effects of return migration, even though return migration from the US to Mexico was quite common at that time (Chort and de la Rupelle 2016; Massey et al. 2016).

We build on the literature in a variety of ways. First, we embed the process of migration within household dynamics more generally. Households change as migrants leave and return but also as members die, new members are born, and others enter and exit along with family changes such as marriage, separation/divorce, and widowhood. Households may also change in complexity as subfamilies are incorporated or break off. All of these changes are relevant to household labor allocation and to livelihood strategies in rural areas (Sherbinin et al. 2008; West 2009). Yet, other than through controls for household size (e.g., Manning and Taylor 2014; also see Alem et al. 2016; Heltbert 2004; Rahut et al. 2016), they are neglected in the literature on migration and fuel use.

Second, consistent with our interest in household dynamics, we view migration as a process, including return as well as out-migration. The literature has focused almost exclusively on migrants departing from the household and has had little to say about return migrants. Yet, the success of migration as a livelihood strategy depends on migrants continuing to meet obligations to the home household or returning when they meet an earnings target. Further, return migration potentially affects household fuel use through the same mechanisms as migration. Just as migrants may remit some part of their earnings, return migrants may bring earnings back with them. Just as migration reduces the availability of labor for fuelwood collection, return migration has the potential to restore it.

Finally, consistent with our interest in migration as a process, especially in the context of household change, we draw on longitudinal data for our study. Longitudinal data enable us to describe and study real change, putting migration into the context of household change generally. It allows us to compare the effects of migrant departures with departures due to marriage, separation, divorce, and death, and to compare the effects of migrant returns with additions to the household through marriage, birth, and other processes. These comparisons help adjudicate between remittances and labor constraints as mechanisms for migration effects. Longitudinal data also strengthen causal inference as we are able to use statistical methods that focus on change and control for unobserved fixed characteristics of households and communities.

Data

Our study is set in rural Zambia, a landlocked country in southern Africa that like many countries in the region has experienced rapid urbanization and rural-to-urban migration over the last few decades (Oucho and Gould 1993; Hedlund and Lundahl 1983). During our study period, 2010 to 2017, Zambia experienced rapid economic growth averaging 6.5% of GDP per capita driven largely by the mining industry. Most of this economic development was concentrated in urban areas and the Copperbelt, motivating migration from rural areas. According to the most recent census, urban places accounted for 39.5% of the population in 2010, up from 34.7% in 2000 (IOM 2019: 48). Net rural-urban migration explains this shift in population (Crankshaw and Borel-Saladin 2018).

Our study sites are located in three remote, rural districts at the periphery of the country: Kalabo and Shangombo districts in Western Province, and Kaputa district in Northern Province (**Figure 2**). These remote districts, among the poorest in Zambia, were largely excluded from rapid economic growth in recent decades (Siedenfeld and Handa 2011). Information about internal migration is not available at the district level, unfortunately, but at the provincial level, according to 2010 census data, net migration was negative in these two provinces, -11.0 per 1,000 in Northern Province and -8.1 per 1,000 in Western Province (IOM 2019: 470). Given their status as border provinces, it is possible that some out-migrants went to Angola (neighboring Western Province) or Democratic Republic of Congo (DRC, neighboring Northern Province), although at the national level, neither Angola nor DRC are in the top 10 destination countries for emigrants from Zambia (IOM 2019: 24). Unfortunately, granular data on emigration from the study districts and provinces is lacking

[1]. However, even if cross-border migration were occurring, it would meet the conditions of a household strategy based on spatial diversification, which is that the economy at the place of destination be largely independent of that in the origin.

We draw on longitudinal data collected as part of an evaluation of Zambia's Child Grant Programme (CGP). The goal of the program was to reduce extreme poverty and the intergenerational transmission of poverty (Seidenfeld and Handa 2011). The CGP targets households with young children (under 5) living in districts characterized by extreme poverty and provides an unconditional cash transfer of 55,000 kwacha per month (~$11) to participating households (regardless of size). In 2010, Zambia's Ministry of Community Development and Social Services rolled out the CGP in three districts: Kalabo, Shangombo, and Kaputa. These are some of the most remote and underdeveloped districts of the country, with poor infrastructure and child health outcomes. At that time, infant mortality was 97 per 1000 live births in these districts' two provinces, amongst the highest in Zambia (DHS 2007).

[1] There is likely not a strong economic pull for emigration to Angola or DRC given that employment opportunities over the past few decades have generally been far better in Zambia or other countries compared to less politically-stable Angola and DRC (Cattaneo and Robinson 2019), and Zambian migrants would face significant language barriers working in formal sector jobs as Angola is Lusophone and DRC is Francophone.

A randomized control trial evaluation of the CGP was conducted by American Institutes of Research (AIR) and the University of North Carolina under contract to UNICEF. The selection of households followed a stratified multistage cluster design, with a random selection of villages within each of the three districts, followed by a random selection of eligible households within each of the selected villages. Eligibility was defined as the presence of a child under three. Baseline data were collected in 2010, before households were randomized into and out of the CGP. We draw on the baseline data and also follow-up surveys conducted in 2013, 2014, and 2017. Importantly, so as not to confound our results with the operation of the CGP itself (Chakrabarti 2019; Mueller et al. 2020), we restrict our analysis to the 1,085 households randomized to the control group and having data from all four waves of data collection[2].

We focus on the use of fuel for cooking, which is the primary use of household energy in our context. For Zambia as a whole, the 2015 Living Conditions Monitoring Survey found that 83.6% of households use biomass fuel as their primary source for cooking; among rural households, biomass fuel use is nearly universal at 97.7%, with 84.5% relying on firewood and 13.2% on charcoal as their primary source (Central Statistical Office, 2016). The rural households in our sample follow a similar pattern, as shown in **Table 1**. Fuelwood was the predominant choice, with almost all households (96.0%) reporting use of fuelwood at baseline in 2010. Over the seven-year

[2] The CGP evaluation includes 2,515 households in the baseline, in which 1259 households were in the control group. The two study arms remained balanced over the survey waves as there was no differential attrition between treatment and control groups. For overall attrition, there are no statistically significant differences in baseline characteristics between the remaining sample at the follow-ups and the sample at baseline, indicating that samples did not change over time (an issue of external validity). Attrition was concentrated in the 24-month wave and focused in Kaputa district , where the drying up of Cheshi Lake forced households relying on the lake for fishing and farming to move. Among our tracked control group households, 3.0% moved their dwelling unit, and 2.3% moved out of the village.

study period, there was a steady decline in reliance on fuelwood, from 96.0% to 88.7 %, while the use of charcoal as a primary fuel source almost quadrupled from 3.2% to 11.2%.

The shift from fuelwood (a traditional least efficient fuel) towards charcoal (a more efficient fuel) reflects the beginning of an energy transition (Heltberg 2004). Previous studies have generally conceptualized the switch from inferior fuels to more advanced and cleaner fuels as moving up an “energy ladder”. However, in our study villages, rather than moving away from inferior fuels completely, half of those using charcoal as their main fuel also used firewood for cooking. The percentage was even higher in 2017 after the prevalence of charcoal had tripled than in 2010. This reflects fuel stacking, where households diversify into a portfolio of energy sources at different points of the energy ladder. Unfortunately, it is too fine a cut to distinguish households that do and do not use fuelwood as a supplementary source among those whose main source is charcoal. Nor is it possible to distinguish the very few households using so-called modern fuels such as LPG and paraffin (collectively less than 1%). In our analysis, we distinguish use of fuelwood from other fuels, and group other fuels such as LPG and paraffin that are uncommon in this setting with charcoal. Thus, we are asking what drivers shift households away from fuelwood as their main source of fuel for cooking, with particular attention to migration and other forms of household change.

We control for the influence of environmental characteristics in our analysis. To measure biomass availability, we use annual tree cover in 5 km buffers around individual households (the longest travel distance of collecting wood, Adkins, Oppelstrup, and Modi 2012; Jumbe and Angelsen

2011; Mlambo and Huizing 2004; Brouwer, Hoorweg, and van Liere 1997)[3]. This information is drawn from the Hansen Global Forest Change dataset (Hansen et al. 2013). As reported in **Table 1**, tree cover decreased slightly between 2010 and 2017. Given the possible influence of temperature and/or rainfall on household fuel use (Rawat et al. 2009; Shackleton et al. 2002), we also compile data on monthly precipitation and temperature from the Climatic Research Unit Time-Series Version 4.02 dataset. **Table 1** shows the average precipitation and temperature in the survey month. The survey months are mainly in October and November, the hot and rainy season. While there is little variation in temperature over waves of the survey, there is substantial variability in precipitation. In 2013, mean precipitation was 29.02 mm in the survey month, a low point, ranging up to a high of 91.11 mm in 2017. To deal with skewed distributions or extreme values, we apply the Inverse Hyperbolic Sine (IHS) transformation[4] to the three environment variables in the regression analysis.

Table 1 also presents information about household economic status over waves. Daily expenditure per capita increased by almost half between 2010 to 2017, consistent with the overall growth experienced in Zambia during this period. Despite the improvement, these are extremely poor households. The average expenditure per capita per day is about US$ 0.32, and as a point of reference, the international poverty line is US$ 1.90 (Ferreira et al. 2016). Since income is a mediator of the effects of migration on fuel use, the inclusion of income in regressions would

[3] We also test robustness lagging tree cover by 1 year; results are qualitatively similar and available upon request.
[4] The inverse hyperbolic sine (IHS) is a transformation that is defined for all values, including negative and zero (Burbidge and Magee 1988):

$$\ln\left(\theta D_{it} + (\theta^2 D_{it}^2 + 1)^{\frac{1}{2}}\right)/\theta = sinh^{-1}(\theta D_{it})/\theta$$

where $\theta = 1$ in our transformation and the inverse sine is approximately equal to ln $(2D_{it})$, except for small value (e.g. less than 1), so it can be interpreted in the same way as a natural logarithmic transformation (Pence 2006; Friedline et al. 2015).

control away the processes of interest. We instead control for community level economic status with the mean community asset index[5] (Handa et al. 2018), which increased 51% between 2010 to 2017.

We now turn to the determinants of chief interest: household size, composition, and change. This information was derived from detailed household rosters collected at baseline and updated at each subsequent wave of data collection. As shown in **Table 2**, households change quite a bit. Much of the change revolves around children. As shown in the table, new members largely consist of births and young children under 10 years of age. Quite a few of these children leave the household as well, perhaps reflecting patterns of child fostering (Grant and Yeatman 2012) or possibly reporting and tracking challenges with this age group. Household dynamics are not limited to young children, however, as older children over 10 and adults also enter and exit households. Considerable movement into and out of households characterizes each inter-survey interval, with the amount depending in part on the width of the interval, although departures consistently exceed arrivals by a substantial margin. Among departures, no matter the survey interval, about half move locally within the same or a nearby village, and the other half move to a more distant town, city, or even Lusaka. Mean household size slightly increased over the seven-year period, from 5.7 in 2010 to 6.1 in 2017. Households do not report receiving remittances very often (2.2.% on average). It is possible that migrants brought money with them when they returned (Tong and Piotrowski 2010).

[5] This index is based on productive assets. We checked robustness by comparing results with those found with a domestic asset index and a livestock asset index. Results (available on request) are qualitatively similar and consistent.

Empirical Strategy

Our analysis focuses on the potential effects of migration and other changes in household size and composition on fuel use. Some previous studies treat migration as an endogenous variable (Manning and Taylor 2014; Rozelle et al. 1999), which raises the possibility of reverse causality if prior fuel use affects fuel availability, and fuel availability in turn drives migration. However, we do not believe that is the case for our study. First, the amount of tree cover within a 5 km buffer of each survey household is fairly steady over the survey years, which is not what we would expect if fuel use were driving fuel availability. Second, we tested whether the tree cover within a 5 km buffer of migrant households was less than the tree cover in 5 km buffers of non-migrant households and found no significant difference [6]. Third, we performed a Durbin-Wu-Hausman test, which suggests that migration is not endogenous to firewood use decisions[7]. Finally, given that fuelwood availability could be a determinant of fuel use, we control for fuelwood availability by including tree cover around 5 km buffers of households.

We model fuel use with a binary variable, which equals 1 if fuelwood is the main source of cooking fuel for the household, 0 otherwise. While Logit or Probit models have been used widely to estimate binary variables, these nonlinear probability models (NLPM) suffer the difficulties of interpretation. Logit, Probit, or other NLPM do not separately identify the mean and variance, thus when comparing coefficients within the same model, interpretations will be determined by the assumptions on which the model is based (Breen et al. 2018; Cameron & Heckman 1998). They

[6] Two-sample t-test (unequal variances) is performed under the null hypothesis that the difference between tree cover around migrant households and tree cover around non-migrant households is greater than zero. P-values are greater than 0.9 for the 3 tests in each follow-up year.

[7] The regressions performed are based on the same fixed effects linear probability model; P-values are greater than 0.2 in all instances. Results available upon request.

also create problems for comparisons of coefficients across different models, as the residual standard deviations of the models differ (Breen et al. 2018; Breen et al. 2014; Karlson et al. 2012; Mood 2010; Allison 1999). We adopt the linear probability model (LPM)[8], which is preferable to the Logit or Probit models when the purpose is to compare and interpret coefficients within and between models (Breen et al. 2018).

To model panel data, we use a fixed effects model, which avoids the problem of heterogeneity bias and controls out time-invariant variables, both those that are observable and those that are not (Allison 2009). We include year fixed effects to capture the time trend and control for characteristics of households and communities that change over the years. Our fixed effects linear probability model can be written as:

$$F_{it} - \overline{F_i} = \beta_1(M^o{}_{it} - \overline{M^o}_i) + \beta_2(M^r{}_{it} - \overline{M^r}_i) + \beta_3\left(H^d{}_{it} - \overline{H^d}_i\right) + \beta_4(H^e{}_{it} - \overline{H^e}_i) + \beta_5(R_{it} - \bar{R}_i) + \sum_{j=6}^{j} \beta_j(x_{itj} - \bar{x}_{ij}) + (\varepsilon_{it} - \bar{\varepsilon}_i)$$

where F_{it} is a binary variable reflecting fuel use, M^o represents number of out-migrants, M^r represents number of return migrants, $H^d{}_{it}$ represents other departures from the household, $H^e{}_{it}$ represents other entrants to the household, R_{it} represents presences of remittances, x_{itj} represents time-variant controls for household i in time t, and year fixed effects. ε_{it} represents the residuals. $\overline{F_i}$, $\overline{M^o}_i$, $\overline{M^r}_i$, $\overline{H^d}_i$, $\overline{H^e}_i$, $\bar{R}_i$, $\bar{x}_{ij}$, and $\bar{\varepsilon}_i$ represent individual i's mean across all years, which account for the between effect. $(F_{it} - \overline{F_i})$, $(M^o{}_{it} - \overline{M^o}_i)$, $(M^r{}_{it} - \overline{M^r}_i)$, $\left(H^d{}_{it} - \overline{H^d}_i\right)$,$(H^e{}_{it} -$

[8] To check the robustness of our results to this choice of specification, we estimated a parallel logit random effects model. Results are qualitatively similar (available upon request).

$\overline{H^e}_i$), $(R_{it} - \bar{R}_i)$, $(x_{itj} - \bar{x}_{ij})$ and $(\varepsilon_{it} - \bar{\varepsilon_i})$ measure variation within individual households over time, which account for the within effects. Considering the heteroskedasticity that arises with the LPM (Breen et al. 2018) as well as the clustered nature of the sample, we estimate robust standard errors (also known as the sandwich estimators), which are clustered at the community level.

Building on our arguments, and consistent with the specifics of the case, we advance the following hypotheses about the coefficient estimates in the equation above: (1) β_1 is negative, out-migrants will decrease the use of fuelwood, especially migrants to distant (likely urban) places; (2) β_2 is ambiguous, the balance of the positive effects of return migrants through increased labor supply and negative effects through possible resources brought home; (3) β_3 is negative, other departures from the household will decrease the use of fuelwood; (4) β_4 is positive, other entrants to the household may increase the use of fuelwood, but it depends on the relative numbers of births to adults; (4) β_5 is negative, remittances likely decrease the use of fuelwood.

Results

Table 3 reports average marginal effects of migration and other changes in household membership on the probability of fuelwood use. There are nine model specifications. The first examines the effect of net change in household size on fuel use. Subsequent specifications decompose that change in a variety of ways, distinguishing exits from entries and then different types of exits (migration, death, and other household change) and entries (births, return migration, and other household change). One specification distinguishes male and female entries and exits. These decompositions enable us to measure the effect of migration on fuel use in the context of household change, to consider return as well as out-migration, and to compare the effects of migration to other changes in household membership. A final specification examines the effect of remittances, although as we have noted, very few households report receiving them. In each specification, we control for the number of household members that did not change from the previous wave, the age of household head, tree cover, electricity access, community assets, precipitation, temperature, and year fixed effects.

As shown in model (1), net change in household membership has a weak and nonsignificant effect on use of fuelwood, and decomposing net change into exits and entries in model (2) also produces weak and nonsignificant effects.

Models (3) through (6) explore household exits. Differentiating migrants who moved to distant (likely urban) places from other exits from the household in model (3) shows the expected negative effect for the migrants, but it is not statistically significant. Model (4) decomposes departures into local movers (same or nearby village), more distant migrants, and deaths. Model (5) further differentiates local movers into those moving within the village and those moving to a nearby village. Each exit has a negative effect on the use of fuelwood as the main energy source for cooking, as expected. The loss of a migrant has a marginally significant effect compared to no effect, although it is not significantly different from the effects of the other exit types. When household members leave for more distant urban areas, those left behind are less likely to use firewood as their primary fuel for cooking. More precisely, the departure of each household member to an urban area leads to a decrease of 0.019 in the probability of using firewood as a primary fuel for cooking. The effect is robust across model specifications. Given that women in LMICs are often responsible for fuelwood collection, model (6) divides departures into male and female, but again, while the estimated effects are negative, they are very weak, not significantly different from each other, and not significant overall.

The results suggest that out-migration shifts households away from fuelwood as a primary source for cooking, with a particular role for long-distance migrants. Two different mechanisms could be responsible: the loss of productive labor and/or increases in income. Longer-distance migrants are more likely to be in the urban labor market and get better payment from off-farm employment. Local migrants are more likely to be working as agricultural day laborers, generally making less money (if paid in cash) than longer-distance migrants in urban areas. Thus, the probability of sending back remittances and the amount of remittances are both larger for long-distance migrants. On the other hand, local migrants living in the same or nearby villages can more easily come back and help. That is, the labor constraint could be released and the effect of lost labor on fuel use weaker for local migrants.

Turning now to household entries, model (7) decomposes them into births, returned migrants, and other (mostly children, as shown in Table 2). Although as noted earlier, births and the movement of children into study households are common, they have little effect on use of fuelwood. However, returned migrants have a strong and significant positive effect, an effect that is robust to the treatment of household departures, the difference between models (7) and (8). For each migrant who returns, the probability that the household uses fuelwood as a primary source for cooking increases by an amount between 0.040 in model (7) and 0.051 in model (8). While returned migrants may bring resources and cash back with them, they also contribute to labor force in the household. With more labor available to collect fuelwood, the household is more likely to use fuelwood as the main source of cooking.

Support for both labor availability and income hypothesis can be found in model (9), which includes a measure of remittance. If remittances were responsible for the effect of migration on fuel use, we would expect to see a decrease in the use of fuelwood and further, as a potential mediator, to see the effects of the migration variables weaken. As shown in model (9), the effect of remittances on fuelwood use is negative and statistically significant, as anticipated, but the estimated effects of the migration variables do not change with its inclusion. In other words, remittances do not appear to mediate the effects of out- or return migration. This pattern of results suggests that both labor allocation and remittances are mechanisms relevant to the effect of migration on fuel use.

Finally, when household dynamics are taken into account, the count of members unchanged since the last wave has no remaining effect. This does not mean that household size does not matter to patterns of fuel use. Households become larger and smaller through migration, marriage, fertility, and mortality. Larger households have lost fewer members through migration, marriage, and mortality and gained more members through marriage, fertility and return migration. Our decompositions in **Table 3** show the importance of migration to the effects of household size in our dynamic models. Households made larger through migration are more likely to use fuelwood as their main energy source for cooking, while households made smaller through migration are less likely. These effects correspond with the general literature, which shows a positive effect of household size (Muller and Yan 2018; Özcan et al. 2013; Rao and Reddy 2007; Ouedraogo 2006; Reddy 1995), but additionally, shed light on how the effect is achieved in this setting.

With respect to control variables, the dominance of tree cover in 5 km buffers has a positive but insignificant effect, which suggests that availability is not a key determinant of household reliance on fuelwood in our setting. Precipitation also does not affect fuelwood use. Average temperature (in the survey month), however, does: increases in temperature decrease fuelwood use. Electricity accessibility also makes a difference, as once a household gains access to electricity, it is less likely to use fuelwood as its main cooking fuel. Finally, as shown in the significant negative effect of the asset index, households in wealthier communities are less likely to rely on fuelwood for cooking than those in less well-off communities.

Conclusion

Our study is the first to model the dynamic effects of migration on household fuel use in sub-Saharan Africa. We leveraged intra-household variation in household membership over time and the use of firewood as a primary cooking fuel in an analysis based on panel data collected in three districts of rural Zambia. Whereas previous studies largely have relied on comparisons between households with and without migrants for their inferences, we looked instead at how individual households respond when one of their members migrates. Our fixed-effects analyses suggest that migration to distant areas helps move households away from traditional fuels toward more modern fuels.

Importantly, we considered migration as a process. Whereas prior studies restricted their attention to out-migrants only, our study also took account of possible return migrants. Both are potentially relevant to fuel use. Just as out-migration may increase labor constraints, making fuelwood collection more difficult, return migration may ease them. Both affect fuel use in rural Zambia, according to our results. Furthermore, they are linked. The success of migration as a livelihood strategy depends on migrants continuing to view themselves as members of and obligated to their original household, contributing to its welfare through remittances, possibly returning once they have reached their earnings target. Looking only at out-migration risks missing half of the story.

Finally, migration can affect fuel use both through its implications for labor allocation and through its implications for remittances. To the extent that labor allocation is the explanation, then other changes in household size and composition should have similar effects as migration. To the extent that it is income, then remittances should have an effect on fuel use. The results of our analysis suggest that both play a role in this setting. We find direct evidence for the importance of remittances. Evidence for the importance of labor availability is more indirect. First, while the effect of long-distance out-migration differs significantly from zero, it does not differ significantly from the effects of shorter-distance migration. Second, the effect of return migration is significantly positive, consistent with a relaxed household labor constraint, rather than negative, reflecting a possible income effect. Third, the effect of out- and return migration does not change even when remittances are controlled. Our analysis results are consistent with the fact that the cost of labor for collecting fuel is greater than the cost of purchasing fuel in our study region[9]. Thus,

[9] Gathering firewood incurs a non-trivial opportunity cost to the household. From the last survey wave in 2017, the cost of time/labor to collect fuel per 4 weeks is 67.7 ZMW for adults (45.15 ZMW for children) based on the average amount of time spent gathering firewood as reported by households, and the local wage. Meanwhile expenditure on fuel in the four week reference period from the survey data is 46.7 ZMW. If we account for the

households would shift from collected firewood to purchased fuel, especially when they face a tighter labor constraint and looser budget constraint.

It is important that these results be replicated in different settings and among different populations. First, the three districts represented in this study are remote and underdeveloped, examples of extreme poverty. Our results are thus most generalizable to similar contexts in rural sub-Saharan Africa. The particular tradeoff of labor availability and remittance effects associated with migration may not generalize to less-remote settings where migration is less costly due to well-established migration streams connecting rural to urban areas. It also may not generalize to places with a better developed local economy, including off-farm employment opportunities (cf. Gong 2011; Wang et al. 2012). Second, the households used in our analysis were selected based on eligibility for the Child Grant Programme, defined as the presence of a child under three. Our study thus captures households at a particular moment in the life course characterized by labor constraints. The availability of labor for fuelwood collection may be especially important in these households.

These caveats notwithstanding, our study contributes to the literature on determinants of household energy use, providing evidence that migration affects households' fuel choices in the context of extreme poverty. Improving access to more efficient sources of energy for poor households in developing countries has been a major challenge for global development. While effort in promoting modern energy transition has been increasing, there remain questions about which

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transaction cost of purchasing fuel which is dominated by transportation cost to market, 5.5 ZMW (travel time to market multiplied by adult average hourly wage), the total cost of purchasing fuel is 52.2 ZMW. The opportunity cost of labor for collecting fuel is still greater than the cost of purchasing fuel. This explains why households would shift from collected firewood to purchased fuel, especially when they face a tighter labor constraint.

approaches are the most effective at reducing energy poverty. Our results suggest a role for migration in this transition. We expect this finding has implications in broad areas of sub-Saharan Africa, where most rural and poor urban households depend on biomass for their cooking needs (IEA 2019).

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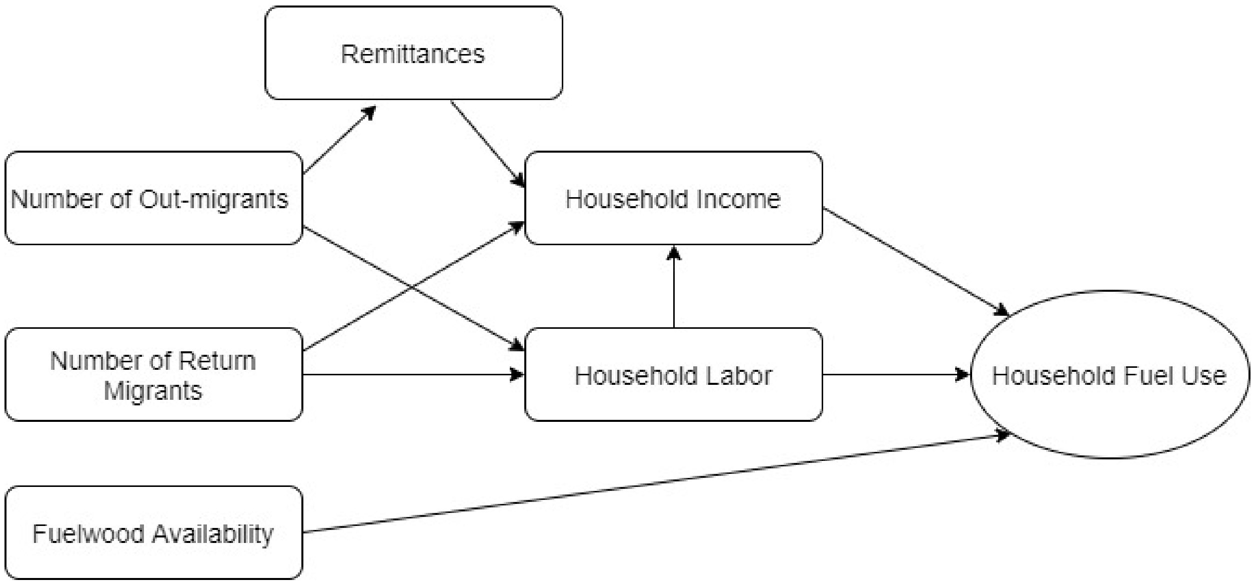

Figure 1 The Effects of Migration on Fuel Use

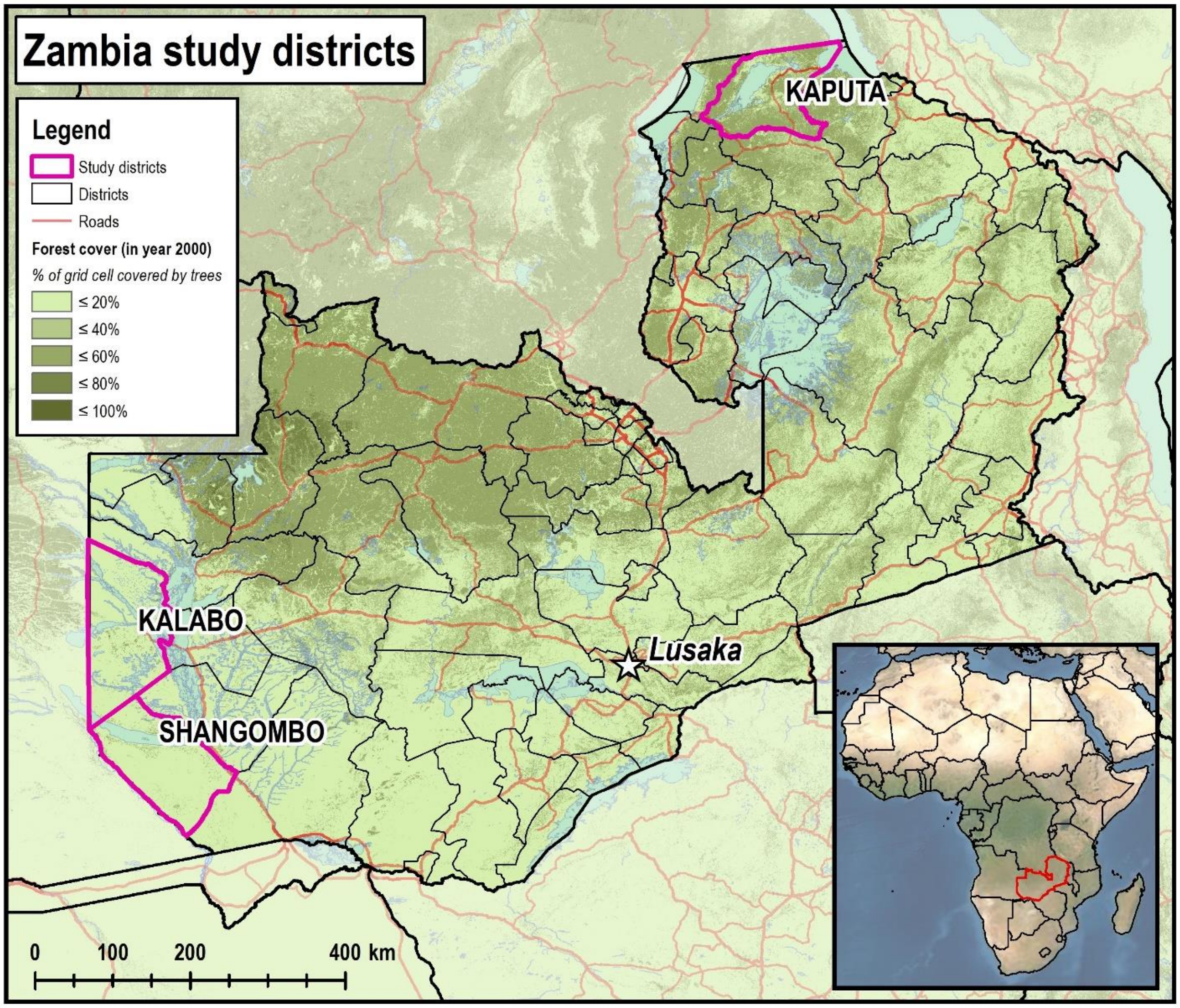

Figure 2 Study Area

Table 1 Fuel Use, Environment Characteristics, and Economic Status Over Waves

	Baseline (2010)	**36 month follow-up (2013)**	**48 month follow-up (2014)**	**84 month follow-up (2017)**
Main source of cooking fuel (% of households)				
Firewood	96.04%	94.98%	95.90%	88.74%
Charcoal	3.23%	4.84%	4.01%	11.16%
Others	0.74%	0.19%	0.09%	0.09%
Purchased vs. collected fuel as the main source of cooking fuel				
Purchased firewood	1.54%	2.64%	1.55%	2.83%
Purchased charcoal	25.71%	26.92%	48.84%	37.50%
Fuel stacking				
Among households using firewood as the main source, % that also use charcoal	3.65%	3.33%	4.96%	6.39%
Among households using charcoal as the main source, % that also use firewood	45.71%	30.77%	60.47%	53.33%
Numbers of fuels used in the family, mean (standard deviation)	1.14	1.06	1.08	1.13
	(0.37)	(0.25)	(0.28)	(0.35)
Access to electricity	0.65%	0.19%	0.66%	1.02%
Environment characteristics mean (standard deviation)				
Tree cover in 5km buffers, km^2	12.18	12.11	12.10	12.03
	(6.32)	(6.28)	(6.26)	(6.20)
Average precipitation in the survey month, mm	69.61	29.02	75.91	91.11
	(21.50)	(12.27)	(21.89)	(45.64)
Average temperature in the survey month, C◦	26.24	25.61	25.31	25.70
	(0.55)	(0.50)	(0.74)	(0.62)
Economic status mean (standard deviation)				
Total expenditure per capita per day (2010 USD)	0.26	0.33	0.31	0.37
	(0.21)	(0.23)	(0.19)	(0.29)
Share of food as part of total expenditure	71.96%	74.86%	75.21%	70.83%
	(14.80 %)	(10.86%)	(10.63%)	(14.29%)
Mean of asset index in the community	0.60	0.75	0.77	0.78
	(0.13)	(0.12)	(0.14)	(0.14)

Table 2 Household Changes Over Waves

	Baseline (2010)	36 month follow-up (2013)	48 month follow-up (2014)	84 month follow-up (2017)
Household dynamics[1]				
Household size (mean)	5.63	6.08	6.03	6.11
New members (mean)		0.07	0.21	0.50
Births		64.47%	57.96%	26.46%
Others age <10		14.47%	21.68%	56.75%
age 10-14		2.63%	6.19%	3.28%
age 15-19		3.95%	4.42%	3.28%
age 20-24		0.00%	1.33%	2.55%
age 25-29		1.32%	2.65%	0.73%
age 30-34		3.95%	0.00%	2.19%
age 35-39		5.26%	1.33%	1.46%
age 40-44		1.32%	0.00%	1.09%
age 45-49		0.00%	1.33%	0.36%
age 50+		2.63%	3.10%	1.82%
Departing members (mean)		0.43	0.70	1.11
Children<10		28.36%	26.44%	18.14%
age 10-14		19.83%	16.75%	14.67%
age 15-19		18.55%	18.19%	17.23%
age 20-24		11.73%	14.01%	16.49%
age 25-29		7.89%	8.38%	9.48%
age 30-34		3.84%	4.32%	6.92%
age 35-39		2.35%	2.36%	4.20%
age 40-44		1.92%	2.36%	3.79%
age 45-49		0.85%	1.18%	2.23%
age 50+		3.84%	6.02%	6.84%
Presence of remittances		1.22%	2.53%	2.95%

Notes:
[1] The changes in household composition are measured between the current and one lagged wave. The changes in the column of 36 month follow-up (2013) are compared to the 30-month follow up (2013). The analysis excludes the 24-month and 30-month follow up due to missing data of fuel use or other variables of interest. Because "departing members" counts all leaving people rather than people that new left in the current wave, household size in a current wave equals to the cumulative sum of household size and new members in one lag wave plus new members and minus departing members.

Table 3 Fixed-Effect Linear Probability Model Average Marginal Effects on Firewood Use

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Net change	0.003								
	(0.006)								
Exits		-0.005					-0.007		
		(0.008)					(0.008)		
Leave local				-0.021					
				(0.019)					
Leave same village					-0.035			-0.036	-0.038
					(0.028)			(0.038)	(0.038)
Leave nearby village					-0.012			-0.015	-0.017
					(0.023)			(0.029)	(0.029)
Leave distant (migrants)			-0.019	-0.019*	-0.019*			-0.019*	-0.019*
			(0.012)	(0.010)	(0.011)			(0.010)	(0.010)
Die				-0.014	-0.014			-0.025	-0.026
				(0.015)	(0.015)			(0.017)	(0.016)
Leave Male						-0.002			
						(0.011)			
Leave Female						-0.010			
						(0.007)			
Other Exits			0.001						
			(0.008)						
Entries		-0.008	-0.007	0.002	0.002	-0.007			
		(0.008)	(0.008)	(0.009)	(0.009)	(0.008)			
Returned Migrants							0.040*	0.051**	0.051**
							(0.020)	(0.024)	(0.024)
Born							0.003	0.003	0.003
							(0.007)	(0.007)	(0.007)
Other Entries							-0.020	0.004	0.004
							(0.016)	(0.031)	(0.031)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Remit									-0.063**
									(0.028)
Same members	0.002	0.001	0.000	-0.001	-0.002	0.001	-0.000	-0.002	-0.003
	(0.007)	(0.008)	(0.008)	(0.006)	(0.006)	(0.008)	(0.008)	(0.006)	(0.006)
IHS(Tree cover)	1.650	1.656	1.593	1.661	1.664	1.662	1.608	1.619	1.562
	(2.201)	(2.185)	(2.193)	(2.185)	(2.185)	(2.191)	(2.157)	(2.145)	(2.123)
IHS(Precipitation)	0.013	0.014	0.014	0.013	0.013	0.014	0.013	0.012	0.011
	(0.017)	(0.017)	(0.018)	(0.018)	(0.018)	(0.017)	(0.017)	(0.018)	(0.019)
IHS(Temperature)	-0.738*	-0.747*	-0.747*	-0.782*	-0.781*	-0.750*	-0.670	-0.668	-0.671
	(0.414)	(0.419)	(0.413)	(0.416)	(0.416)	(0.419)	(0.418)	(0.408)	(0.407)
Electricity access	-0.165**	-0.160**	-0.161**	-0.161**	-0.162**	-0.159**	-0.159**	-0.163**	-0.165**
	(0.072)	(0.073)	(0.073)	(0.073)	(0.072)	(0.073)	(0.074)	(0.071)	(0.071)
IHS(Head age)	0.006	0.004	0.003	-0.003	-0.002	0.005	0.004	-0.006	-0.006
	(0.038)	(0.038)	(0.038)	(0.041)	(0.041)	(0.038)	(0.039)	(0.043)	(0.043)
Community asset index	-0.270***	-0.271***	-0.271***	-0.271***	-0.269***	-0.273***	-0.266***	-0.266***	-0.264***
	(0.074)	(0.074)	(0.074)	(0.074)	(0.074)	(0.075)	(0.072)	(0.072)	(0.071)
Constant	-1.147	-1.112	-0.912	-0.941	-0.963	-1.115	-1.258	-1.249	-1.054
	(6.553)	(6.577)	(6.623)	(6.504)	(6.495)	(6.587)	(6.530)	(6.433)	(6.371)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	4287	4287	4287	4287	4287	4287	4287	4287	4287

Notes:
These are average marginal effects (the average of the individual marginal effects) on the probability of fuelwood use.
IHS represents Inverse Hyperbolic Sine transformation.
Standard errors in parentheses.
"***", "**", "*", indicate significance at the 1%, 5%, and 10% level.