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Unbelievable but True — Improved cook-stoves are not helpful in reducing firewood demand in Nepal

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Kristine Grimsrud

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South Asian Network for Development
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Abstract

This paper analyzes the effect of different types of cook-stoves on firewood demand at the household level. Using nationally representative household survey data from Nepal we find that stove type significantly affects the firewood demand for household uses. Traditional mud stove user households seem to use less firewood than the open-fire stove users. Surprisingly, households with the so called 'improved' stoves seem to use more firewood than the households with mud stoves. Thus, converting traditional open-fire stoves to mud stoves may be a better conservation strategy in the short term rather than installing improved stoves, unless the technology improves. However, in the long run, making cleaner fuel more accessible to rural households is desirable to reduce indoor air pollution.

Key Words: Firewood consumption, Improved stove, Mud stove, Open-fire stove, Deforestation

JEL Classification**:** Q23, Q42

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1. Introduction

In developing countries, biomass remains the most widely used fuel type. Firewood takes the biggest share of it. Burning biomass for household energy is mainly related to indoor air pollution that causes numerous health problems, emission of greenhouse gases, brown clouds and black carbon (Edwards *et al*., 2004; Chengappa *et al*., 2007; Pant, 2008; Malla, 2009; Gustafsson *et al*., 2009). Deforestation and climate change are interlinked where deforestation combined with natural decaying of biomass is contributing more than 17% of the CO_2 emissions globally (IPCC, 2007). While the debate on the link between fuelwood use and deforestation is far from over (e.g. Arnold *et al*.., 2006), scholars have attributed one major reason for deforestation to the extraction of wood for fuelwood, charcoal, polewood, and the commercial harvesting of forest products (Geist and Lambin, 2002).

Two successive Nepal Living Standard Measurement Surveys (NLSS I and II) indicate that the use and collection of firewood seems to be increasing over years in Nepal. In 1995/96, about 77% households reported that they were using firewood for cooking and 84% of those firewood users collected it (CBS, 1996). However, in 2003/04 about 84% households use firewood for cooking, and 88% of these firewood user households collect it (CBS, 2004). Such a widespread and increasing trend in firewood collection and use may have two potential impacts: it may well threaten the sustainability of Nepal's forests resources and also causing the negative health impacts due to indoor air pollution (Pant, 2008; Malla, 2009) given that very small number of households are using the improved cook-stoves.

Historically, deforestation in Nepal is due mainly to expansion in agriculture, illegal timber extraction, and firewood collection (Bajracharya, 1983). To avoid the massive deforestation, Nepal government started transferring the user rights of the government managed forests to the local communities to manage locally under the widely celebrated community forestry program. While transferring the forest to the local communities during 1980s, Nepal government also try to distribute improved cook-stoves in a limited scale hoping that these cook-stoves would be able to reduce firewood demand. In principle, alternative energy sources, such as electricity, solar, bio-gas, etc., can be used in place of dirty energy, such as firewood. However, replacing the current use of firewood by such alternative energy sources may not be feasible given the current state of electricity generation and its coverage,[1] and unavailability of relatively cleaner energy sources in Nepali villages.[2] One possible solution would be to change cooking stoves that would consume less firewood. The expectation is that such energy efficient cooking stoves may help to reduce firewood consumption and reduce the emissions at the household level. The improved cook-stove (ICS) technology was first introduced in Nepal in the 1950s and its use has been on

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1 Less than 40% households have access to electricity, and during the dry season, the power outage can go on for over 16 hours per day during dry season.

2 About 8% households in Nepal (mostly concentrated in the Kathmandu valley and few other urban centers) use Liquefied Petroleum Gas (LPG), and additional 5% use kerosene stoves for cooking purpose in Nepal (CBS, 2004).

the rise since the latter part of the 1990s. NLSS data indicate that the ICS program has country-wide coverage that households in 31 out of 75 districts have reported the use of ICS in 2003/04 survey.

This paper investigates the impact of different types of cook-stoves on firewood consumption in Nepal. More specifically, we want to investigate whether households with improved stoves use less firewood than households with the traditional mud stove or the open-fire stove. Many types of cooking stoves are in use throughout Nepal. If an improved stove consumes less firewood than mud or open-fire stove while meeting the household's energy need, then, the adoption of such less firewood consuming cook-stove may help to maintain the sustainable use of firewood. This may be helpful in reducing indoor air pollution and lowering the pressures on the existing forests resources.

We use data from the Nepal Living Standards Survey 2003/04 for empirical analysis. This is the most recent and the comprehensive household survey in Nepal. It provides socioeconomic and demographic information of the households, such as income, consumption, firewood collection, stove types, health, education, etc. For this analysis, household level firewood consumption is used as the outcome variable. After controlling for different variables, such as average time to collect one *bhari*[3] of firewood, household size, number of animals (cows and buffalos), we find that the type of cook-stoves significantly affects the amount of firewood demand. More specifically, we find that the improved stoves are not really improved in terms of firewood saving. Households with traditional mud stoves seem to consume less firewood than households that use the so called 'improved' stoves. The results are not significantly different across different functional forms and different estimation methods after correcting for endogeneity in stoves adoption.

The paper is organized as follows. In the next section, we provide a short review of the related literature. Section 3 presents a brief history of ICS in Nepal. A basic theory, the econometric model, and the hypotheses of the study are presented in section 4. Data and the variables used in the paper are discussed in section 5. Regression results are presented and discussed in section 6. The final section concludes.

2. A Brief Overview of Existing Studies

Despite the widespread use of firewood in developing countries and its potential impacts on indoor air pollution and deforestation, the literature on the contribution of improved stoves to firewood saving is very limited. Cooke *et al*. (2008) provide a review of empirical literature from three developing countries on the adoption of improved cook-stoves. They document that the empirical evidence is inconclusive on the role of improved cook-stove on fuelwood demand. Zein-Elabdin (1997) gives two reasons for the scarcity of the research on the impact of improved stoves on fuelwood demand in developing countries: lack of databases and the lack of understanding on the market for traditional fuels, such as firewood.

Using time-series data, Zein-Elabdin (1997) estimates the demand and supply elasticities for charcoal in Khartoum (Sudan) in order to analyze the rebound effect of new technology adoption. Rebound effect is the behavioral response that offsets the beneficial effect of new technology. For example, if a new technology improves stove efficiency by 20% and fuelwood consumption drops by 15%, then the 5% differential between the fuel efficiency and the decrease in fuelwood

[3] *Bhari* is a local unit of firewood where one *bhari* is a bundle of firewood one can carry. Its average weight is 30-35 kilograms (approx).

demand may be due to an increase in consumption of fuelwood as a result of efficient stoves. The author indicates that such 'rebound effect' gets larger if household's budget share on fuelwood is large, the income elasticity of fuelwood demand is high, and the supply elasticity is low. Zein-Elabdin (1997) study is based on the market data in an urban environment. The author finds increased fuelwood consumption (charcoal) with efficient stoves. This is because the income elasticity of fuelwood demand is very high in the case study where efficient stoves reduce the demand for fuelwood in the first place. Lower demand, however, reduces the price of charcoal. As a result, households adopt cheaper fuel in alternative uses leading to overall higher demand for fuelwood.

But other studies have shown that the use of fuel efficient cooking stoves could reduce the demand for fuelwood. Studies from China (Edwards *et al*., 2004), Guatemala (McCracken *et al*., 1998), India (Chengappa *et al*., 2007), Madagascar (Bazile, 2001), Mexico (Masera *et al*., 2007), and Tanzania (Makame, 2007) show mixed impacts of the improved stoves on fuelwood saving. However, the diffusion of the new technology is not smooth in most of these countries except in China. The main reason of slow or no diffusion of cook-stoves is attributed to the stove designs that sometimes do not meet the cooking requirements of the households.

Sinton *et al*. (2004) provide a detailed account of how the diffusion of the improved cook-stove became successful in China. On the other hand, Barnes *et al*. (1993) provide an excellent review of diffusion of the improved stoves and provide explanation of why households remain reluctant to adopt the new technology in many developing countries. This review highlights the importance of responding to the specificity of the local conditions when introducing a new technology. Basically, the authors claim that while the scarcity and higher price of fuelwood may help the dissemination of the improved stoves, their adoption is not guaranteed. In a related review article, Barnes *et al.* (1994, p v) summarize the conditions for the success or failure of the improved cook stoves adoption as, "no matter how efficient or cheap the stove, individual households have proved reluctant to adopt it if it is difficult to install and maintain or less convenient and less adaptable to local preferences than its traditional counterpart." The emphasis is that the improved stove should not be totally different from what households have been using; it should be improved but not totally new to the users. Using survey data from two rural villages in Nepal, Amacher *et al.* (1992) find that household characteristics, income level, and the availability of firewood determine the adoption of the improved stoves.

A related area of research is the contribution of improved stoves on reducing indoor air pollution and time saving. McCracken and Smith (1998) conducted a study in the Guatemalan highlands where they compared the thermal efficiency, emission content, and the length of cooking time between the traditional three-stone fire-stove and an improved Plancha fire-stove. Their experiment revealed that while the improved stoves emitted less $PM_{2.5}$ (fine air pollutant particles that are 2.5 micrometers in diameter or smaller) they took more time to prepare food as compared to the open-fire stoves.

In a study conducted in China, Edwards *et al*. (2004) find that the thermal efficiency that reduces fuel demand mainly leads to combustion inefficiency causing increased greenhouse pollutants and health damaging particulates. Chengappa *et al*. (2007) conducted a study in India similar to what Edwards *et al.* (2004) did in China. They find that the improved stove reduces the $PM_{2.5}$ concentration and CO, improving the indoor air quality. Masera *et al*. (2007) find the same type of results in the case of the Mexican version of the improved stove. Pant (2008) and Malla (2009) study the health impact of indoor air pollution using small surveys in a few Nepali villages.

Both of these studies find that the improved stoves help to reduce the respiratory diseases significantly. Malla's study that covers five villages from one district (400 households) indicates that the improved stoves can help reduce the use of firewood. Pant's study that covers six villages from two districts (600 households), however, does not analyze the fuelwood efficiency of the cook-stoves.

Results from these studies show that the evidence on the impact of improved stoves on firewood saving, indoor air pollution, and time saving remains inconclusive. However, most of these studies focus mainly on the technical aspects of the stove design using small sample sizes with limited geographical coverage. Our study analyzes the impact of the stove-type on household level firewood consumption with a nationally representative household survey.

3. Improved Cook-stoves in Nepal

The improved cook-stove (ICS) program in Nepal was introduced in the mid 1950s, but its coverage remained very low during the next three decades. The main objectives of the program were to reduce the rate of deforestation along with reducing the indoor air pollution and increasing the efficiency of household energy use. During the 1980s, Nepal government tried to tie up the ICS program with community forestry program in the hope of containing the massive deforestation (Clemens, 2010). In 1999, Nepal government introduced the National ICS Program under the Energy Sector Assistance Program funded by the Danish International Development Agency. At the national level, the Alternative Energy Promotion Center has been administering the program with the help of several organizations, such as the Center for Rural Technology, Nepal (CRT/N), the Department of Women's Development, and other non-governmental and community based organizations.

The ICS program in Nepal is mostly supply driven. Interested organizations have been introducing several types of ICS technologies with different shapes and sizes, such as, mud-brick ICS, and metallic ICS (Practical Action, 2009). The most popular one is the mud-brick ICS. It can have one to three pot-holes, depending on household's requirement. By 2004, the number of ICS in the country was estimated to be 150,000 where CRT/N alone distributed 100,000 mud-brick ICS (Clemens, 2010). The NLSS data suggest that while the use of ICS covers all geographical areas, its rate of adoption is very low with only two percent of households in 31 districts (out of 75) using ICS during 2003/04. Though not identified in the NLSS data set, secondary information indicate that a very few user households adopt the metallic cook-stoves with a damper to regulate the air (Practical Action, 2009).

4. Basic Theory, Econometric Model and Hypotheses

Assume that a representative household derives utility from the consumption of energy (both for heating and cooking), consumption of all other goods, and leisure time. The utility level also depends on household characteristics. A household can get energy from firewood or from alternative sources, such as biomass burning, or petroleum products (e.g., kerosene and LPG). The firewood market is very thin in Nepal. Very few households actually buy firewood in the market, and most of the households collect it rather than buying from the market. Therefore, a market price for firewood is non-existent for most of the households. However, the time spent collecting firewood has an opportunity cost. The opportunity cost could be the returns on household labor. But such information is not available for many households. Thus, we use the collection time as a proxy for firewood price.

Maximizing a household's utility function subject to the budget constraint yields the demand for firewood (see Kohlin and Parks, 2001; Palmer and MacGregor, 2009, for more discussions). For household *i* at the community *j*, the firewood demand (FW_{ij}) is a function of collection time (CT_{ij}), household characteristics (HC_{ij}), and community characteristics (CC_j). The firewood demand also depends on the efficiency of the stove that the household uses. Stove efficiency depends on its type (ST_{ij}). Based on this premise, the reduced form equation for firewood demand is given by the following expression:

$$FW_{ij} = \beta_o + \sum^{3}_{r=1} \beta_r ST_{rij} + \beta_4 CT_{ij} + \sum^{7}_{k=5} \beta_k HC_{kij} + \beta_8 CC_j + u_i \quad (1)$$

There are five types of cook-stoves reported in the survey: open-fire stove (i.e., the traditional tripods type), mud stove, improved stove, kerosene stove, and other. Since the 'other' category is not specified and has very few observations, we use the four types of stove for the analysis.[4] Out of these four stove-types, we use the traditional open-fire stove for comparison. Since the open-fire stove requires more firewood, researchers consider it as the most inefficient of all stove-types (see Edmonds, 2002). The open-fire stove has poor heat transmission because the fire is open in all directions. In comparison, the mud-stove is more enclosed which can transfer more heat energy for cooking. Since we expect other varieties of stoves to be more efficient (i.e. require less fuel) than the open-fire stove, we expect that households would use less firewood if they adopt mud, or improved stoves. Statistically, we expect negative coefficients of these stove types ($\beta_r < 0$). Additionally, we expect that households with improved stove consume less firewood than households with mud stove. So, the coefficient of the mud stove is expected to be smaller in absolute term than the coefficient of the improved stove.

If firewood is a normal good, then an increase in household income should increase the demand for firewood. However, firewood is also the most dirty fuel type generating smoke that causes indoor air pollution. Therefore, with an increase in income a household may want to replace the dirty fuel with a cleaner one, such as kerosene or LPG. As we are using stove types as the main variable on the right hand side, we do not include household income as a control variable to avoid the potential multicollinearity with stove types. Since the collection time (CT_{ij}) is a proxy for the price of firewood, we expect $\beta_4 < 0$.

Another group of control variables is a vector of household characteristics (HC_{ij}), which includes household size (*HHSIZE*), gender of the household head (*MALE*), and the presence of a child below six years (*CHILD*) of age. The rationale for using these control variables is that household size controls for the scale factor, i.e., we expect a positive relationship between household size and firewood demand. As women are mostly responsible for collecting firewood (see Amacher, 1993; Khare *et al.*, 2000), presence of a small child (below six years) in the house may affect the amount of time they can spend on firewood collection.

[4] Question may arise about the rationale of using kerosene stoves while analyzing the firewood demand assuming that when people use kerosene stoves, then there is no question of using firewood. But, in our analysis, we only use households who collect and use firewood. In our sample, and about 95 households use kerosene as well as firewood for household energy.

We also control for the number of big-head animals (cows and buffaloes) as households generally use these animals for milk production (female) and for plowing agricultural fields (males). These animals are mostly fed cooked or warm feed (i.e., a mixture of water, salt, leftover food, rice husk, etc) at least once a day. So, we expect positive effect of number of such animals on firewood demand. We also control for sources of firewood – community forest, government forest and private forest. Since the Government of Nepal initiated the community forestry program with the objective of supplying more forest products (such as firewood, and fodder) while conserving the forest, we expect households with access to a community forest to collect and consume more firewood compared to an access to a government-controlled forest or a private forest.

The literature on the adoption of improved stoves (e.g., Amacher *et al*, 1992; Makame, 2007) indicates that adoption rates mostly depend on the availability of firewood. It may also depend on knowledge about the harmful effects of indoor air pollution or the benefits of the improved stoves, and the location of households. In that sense, the types of stove a household uses could well be endogenously and jointly determined with the amount of firewood a household would demand. Therefore, we instrument the stove-type variable using the ordered logit model as we have four different types of stoves in our sample.

Stove-type may well depend on the cultural factors (such as cooking habits), location (whether hilly or mountain area vs. southern plain area), and the level of education along with the availability of firewood. We, therefore, use the following four variables as a set of instruments: Brahmin/Chhetri (culture), mountain/hills (location), remittance, and education. Here, the first three are the indicator variables, and the last one is household head's years of schooling. The variable related to the cultural factor controls for the cultural traditions of the Brahmin and Chhetri, which are the two dominant high castes in Nepali Hindu society. These two castes generally use the mud stove for cooking their main food items (mostly lunch and dinner), which is generally not the case for other castes/ethnic groups. The reason for including the remittance dummy as an instrument is that when a household member goes away for work and sends money back home, such money may come with attached information. What this means is that the person sending the money may also provide information regarding the negative impact of the indoor air pollution to the family back home if the household is using firewood for household energy.

Finally, the choice of stove also depends on the location of the households. In Nepal, if households are located in the hills or in the mountain region, they mostly use the open-fire stove for keeping themselves warm during winter as well as for drying food grains and other items, such as chilies, during both the rainy summers and the cold winters. During these seasons, the days are either shorter or the sunshine is rare and not enough to dry food grains or other items. The open-fire stove is convenient for these purposes as this type of stove is mainly placed in the middle of the living room so that household members can sit around it to avoid the cold. Above the open-fire stove, households fix a layer underneath the ceiling with enough gap for putting food grains or other items for drying. On the other hand, the mud-stove is mostly placed in a corner of the living room, which prevents household members from sitting around it to avoid the cold, and this kind of stove is not much useful for drying food grains or other items as the heat transmits mostly towards the walls rather than directly towards the ceiling.[5] Given these unique features regarding the locational choice for placing different stove types, we use the mountain/hill dummy as an

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5 This information is based on authors' personal experiences while visiting several villages in the hilly and mountain areas.

additional instrument. We also perform a statistical test in order to verify that our instruments are not directly affecting the firewood demand.

5. Data and Variables

We use the Nepal Living Standards Survey 2003/04 (also called NLSS-II) for the empirical analysis. This survey follows the World Bank's Living Standard Measurement Survey (LSMS) methodology. This is the most recent and comprehensive household survey in Nepal that provides socioeconomic and demographic information of the households (such as income, consumption, labor market, firewood demand, collection time, education, etc). This multi-topic survey consists of a nationally representative sample of 3912 households from 326 primary sampling units (PSUs). These PSUs are selected from six strata using probability proportional to size (PPS) sampling, where size is measured based on the number of households. From each PSU, 12 households are selected systematically (CBS, 2004).

As the main objective of this paper is to investigate the impact of stove types on household-level firewood consumption, we include only a sub-sample of households who collect and use firewood for household energy. We define these households as firewood self-sufficient. In other words, we exclude those household from our analysis who buy firewood, or who collect firewood for selling purpose, and keep only those households who collect and use firewood. In the sample, these self-sufficient households are in majority, and we use firewood collection time as a proxy measure of unit price (as in Amacher, 1993). Additionally, 10 households who reported collecting unusually high amount (more than 40 *bharis*) of firewood per month are also excluded. With such adjustments, our sample size came down to 2607 observations.

Table 1 presents the descriptive statistics of the variables used in the paper. *FIREWOOD* indicates the average monthly firewood collection by households, measured in the local unit *bhari*. In an average a household collects about 7 *bharis* of firewood per month. The average time to collect one *bhari* of the firewood (*COLLECTIONTIME*) is less than 4 hours.

The next four variables are the types of stove used by the households. In our sample, more than 38% households use the most traditional *OPENFIRESTOVE*, 56% households use *MUDSTOVE*, and 2% household use the *IMPROVEDSTOVE*. About 4% households use the *KEROSENESTOVE*.

Other variables used for the analysis are household size (*HHSIZE*), the gender of household head (*MALE*), the number of cows (*COWS*) and buffalos (*BUFFS*) the household owns, the place where the households collect the firewood (community, government or private forest), and an indicator of the presence of a child below six years of age (*CHILD*). The last four variables are used as the instruments. In our sample, about one-third of households receive remittances, and the same fraction of households belongs to the upper caste (Brahmin or Chhetri). About 61% household are from the hill/mountain region and the average years of schooling of household's head is less than three years, meaning that majority of household heads are either illiterate or have very low education.

Table 2 presents the distribution of the same variables by the stove types, which is our main variable of interest at household level. This table indicates that households with open-fire or improved stoves collect more firewood compared to households with mud-stove.

An alternative to firewood collection time as the unit price of firewood could be the opportunity cost of firewood collection time. When the wage rate of hired farm workers increases, the opportunity cost of collecting firewood also goes up for the rural agricultural economy, thus drawing labor away from firewood collection. For the firewood self-sufficient households, the increased productivity of agricultural labor (in terms of the higher wage rate) leads to reduce firewood collection (Palmer and MacGregor, 2009). In our data set, a sub-sample of 757 households hired female farm workers paying cash or in-kind wages. We use the wage rate of these hired female farm workers as the opportunity cost of firewood collection in our analysis. Table 3 presents summary statistics of this sub-sample by stove-type.

6. Results and Discussions

In this section, we present and discuss the regression results. In our model, we use the dependent variable, *FIREWOOD*, in two different ways: in level (Table 4) and in logs (Tables 5 – 7). Similarly, we use *COLLECTIONTIME* in level (Table 4) as well as in logs (Table 5 and Table 7) in order to see how sensitive the results are to the choice of the functional forms.

We estimate ordinary least squared (OLS), two-stage least squared (2SLS), and random effect (RE) models in order to see whether the results are sensitive to a particular estimation method. Firewood collection time could be endogenous (Palmer and MacGregor, 2009). The best way to confirm such endogeneity issue is to perform the Hausman specification test. However, the NLSS data are collected using a two-stage stratified sampling method where our observations are clustered within the primary sampling units (PSU). These PSUs are selected based on the probability proportional to size (PPS) (CEB, 2004). While the Hausman specification test requires one of the estimators to be efficient, such clustered and p-weighted (or PPS) sample observations violate the requirements for the Hausman specification test (StataCorp, 2009).

Another issue is the difficulties in finding convincing exclusion restrictions (i.e., good instruments) in the data set for the *COLLECTIONTIME* that are not correlated with *FIREWOOD* demand. Therefore, we estimate alternative models using the wage rate of hired female farm workers (*FEMALEWAGE*) as a proxy of the opportunity cost of collection time. This wage rate of hired farm workers is exogenous to the households who hire such labor. This alternative comes, however, with a significant cost in terms of smaller sample size of 757 observations, but it is worth doing to find the sensitivity of our resutls. Earlier, with the *COLLECTIONTIME* as a proxy of the unit price of firewood, the sample size was 2607 observations.

Ordinary Least Squared Results

Table 4 displays the regression results where the dependent variable, *FIREWOOD*, is in level. The first two columns (Model-I and Model-II) display the results from the Ordinary Least Squares (OLS) regression where the signs of the coefficients of all stove categories (mud, improved and kerosene) are negative. While estimating these models, we also take into account the clustering and weighting issues of the NLSS data. The results indicate that households that use the mud stove, the improved stove or the kerosene stove demand less firewood as compared to the traditional open-fire stove users. The results also indicate that the *IMPROVEDSTOVE* is comparatively less effective in terms of reducing firewood demand as the coefficient of the improved stove is smaller than the coefficients of other stove types. Additionally, the coefficient of the improved stove is insignificant indicating that households with the improved stoves or open-fire stoves may use statistically comparable amount of firewood per month, *ceteris paribus*.

Results in Table 4 indicate that a household with the *MUDSTOVE* could consume 0.85 *bhari* less firewood per month, or over 10 *bharis* less firewood in a given year compared to a household with the traditional open-fire stove. In the case of the *KEROSENESTOVE*, the monthly firewood saving by a household is about 3.5 *bharis* per month or about 42 *bharis* per year on an average. An interesting result here is the sign of the coefficient of firewood *COLLECTIONTIME*. As a proxy of firewood price, its coefficient is expected to be negative. Though not significant, it is positive. This result, however, is consistent with some other studies (e.g., Malla, 2009). Such a positive price effect indicates that the firewood could be a Giffen good where the demand curve slopes upward. The positive sign of the coefficient of firewood collection time indicates that for the self-sufficient firewood user households from rural Nepal, no cheaper substitutes are available for firewood that they can use when the collection time gets higher.[6]

As expected, household size has a positive and significant effect on firewood consumption. Other variables with positive and significant coefficients are the number of cows and buffalos that households have. The positive coefficient of community forest indicates that households collect more firewood from the community forests as compared to what they do collect from the private or the other forests. This is expected as the one of the main objectives of the community forestry in Nepal is to increase the availability of the forest products, such as firewood, to the local communities (Kanel, 2004).

For the robustness check, we added *CHILD*, an indicator variable for the presence of a below six years old child in the family. Since firewood collection in Nepal is done mostly by women (Amacher, 1993), the presence of a young child may limit their ability to go out and collect more firewood. As expected, the sign of the coefficient of *CHILD* is negative. The signs and the significance of the coefficients of other variables in Model-I and Model-II do not change while adding this new variable, *CHILD*.

While the coefficient of *COLLECTIONTIME* is positive we expect firewood collection time to act as a brake on firewood collection after a certain point. In other words, we expect a non-linear relationship between firewood collection time and firewood demand. One way of addressing this issue is to get log transformation of these variables. So, we replace *COLLECTIONTIME* with its log transformation in Model-III and Model-IV. After such changes, the results are comparable with the first two models except that the sign of the coefficient of the *IMPROVEDSTOVE* is now positive, but still insignificant. These results indicate that on average the *MUDSTOVE* could save about 15% firewood while the *KEROSENESTOVE* could save up to 58% firewood compared to the traditional open-fire stove. However, households with the *IMPROVEDSTOVE* and open-fire stoves could consume comparable amount of firewood as there is no significant difference in firewood demand between mud-stove user and improved stove user households.

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[6] An alternative explanation for the positive sign of the coefficient of the collection time is that in Nepal, underemployment rate is very high. Results from the recent labor force survey (CBS, 2009) indicate that among the employed, only 68% workers worked 40 hours and more in 2008. When collection time increases, household may use additional labor time (as the opportunity cost of the surplus time is negligible) and more effort to collect firewood so that they may wind up collecting more firewood.

Two Stage Least Squared Results

As discussed earlier, the type of stove households use may be endogenously determined depending upon the availability of firewood. If firewood is abundant, households may use open-fire stove, and if no or less firewood is available then family may use some other alternatives, such as, improved stoves or kerosene stoves. We use a two-stage (instrumental variable) estimation approach to address the issue of endogeneity.

As discussed earlier, the choice of the instruments is based on the premise that stove adoption may depend on cultural factors (Brahmin/Chhetri), location of households (mountain/hills), the knowledge on available options, the benefits of using alternative stove types and the harmful effects of the indoor air pollution (education); and the link to the urban centers and beyond in terms of remittance flow. As we have four different types of stoves, we use ordered logit for the first-stage regression.

We test the exclusion restriction for the proposed set of instruments as follows. First, we run regression of *FIREWOOD* on all explanatory variables plus the set of instruments by stove types (open-fire stove and mud-stove, two widely used stove types). Second, we test the joint hypothesis that the set of instruments has no joint significant effect on *FIREWOOD* demand. As we estimate four 2SLS models (see Table 5), we perform the joint significant tests for all four cases. The F-statistic ranges from 0.55 to 1.77 with p-value 0.17 to 0.69 indicating that there is not enough statistical evidence to reject the null hypothesis that the set of instruments has no significant effect on household level firewood demand.

Results from the 2SLS regressions are presented in Table 5. While comparing these results with the OLS results from Table 4, we can see that after instrumenting the types of stove, the coefficient of the *MUDSTOVE* becomes bigger with negative sign, while the coefficient of the *IMPROVEDSTOVE* also becomes bigger but with positive sign. These results indicate that, on average, households with the *IMPROVEDSTOVE* are using more firewood than households with the open-fire, or the mud stoves. This result may seem counter intuitive but it actually confirms what some of the researchers have been reporting on the inefficiency of the improved stoves with regard to fuel-wood consumption and cooking time (see McCracken and Smith, 1998).

Other results in Table 5 are mostly consistent with the results from the OLS estimates (see Table 4). The signs of the coefficients of the *COLLECTIONTIME* (Models-V and VI) and the log(*COLLECTIONTIME*) are stable. As expected, the sign of the *COLLECTIONTIME* squared is negative, indicating that when collection time goes beyond 12 hours (0.276/0.022) for one *bhari* of firewood, households may start switching to other fuels. Given that the average collection time for firewood self-sufficient households is less than four hours in our sample, the turning point seems to be quite far, meaning that those households would continue to collect firewood for household energy conditional on other control factors.

As before, the coefficient of community forest is positive and significant. After correcting for endogeneity, the effect of the presence of children below six years of age is still stable but not strong enough to draw any definite inference. The results are mostly stable with alternative model specifications.

Alternative Measure of Opportunity Cost

So far, we use the time taken to collect one unit of firewood as a proxy measure of the unit price of firewood. However, a better measure of a unit price of firewood would be the opportunity cost of collection time. This opportunity cost could be the wage rate of the person in alternative activity who collects firewood. The NLSS data do not provide information on who actually collects firewood, but Amacher (1993) and Khare *et al*. (2000) find that firewood scarcity results into increased labor burden on women. This indicates that women may be the ones who mostly collect firewood.

In the NLSS data, a small sub-sample of households hired female farm workers for agricultural activities. We utilize this information as a proxy measure of the opportunity cost of firewood collection time. As an individual household has no control over the wage rate of the hired female farm workers, we treat this variable as exogenous.

Table 6 reports the OLS and 2SLS results where collection time is replaced by the wage rate of the hired female farm workers. Again, these results are mostly consistent with earlier ones. From Table 6, we can see that the *MUDSTOVE* user households would consume 18% - 27% less firewood while the *IMPROVEDSTOVE* user households may consume 78% more firewood compared to households that use open-fire stoves. The sign of the coefficient of the *FEMALEWAGE* is negative but not significant. Other results are mostly comparable to what we discussed earlier.

Random Effect Estimates

As an alternative to the simple OLS and the 2SLS estimation methods, we also use the random effect estimator. Our interest here is to examine whether we could get the comparable results from such alternative estimation. The choice of the random effect estimation is based on the argument that in the two-stage stratified sampling, 326 primary sampling units are chosen randomly out of over 36,000 potential units across the country for the NLSS (CBS, 2004).

Table 7 presents the results from the random effect estimator. In terms of the right hand side variables, these results are comparable to Models III and IV in Table 4, and Models VII and VIII in Table 5. In all respects these results are mostly consistent with what we have discussed earlier. The coefficient of *MUDSTOVE* is negative and significant across all models, while the coefficient of *IMPROVEDSTOVE* is positive and insignificant in statistical terms; but it is larger than the coefficient of *MUDSTOVE* in 2SLS models. In practical terms, we can see that households that use mud-stove could consume up to 25% less firewood in an average, whereas improved stove user households could consume over 37% more firewood compared to the open-fire stove user households see Model XIV).

7. Conclusion

This paper analyzes the effect of stove-type on firewood consumption at the household level in Nepal. Using nationally representative household survey data from Nepal, we find that the type of stove significantly affects firewood demand for household uses. For this analysis, we use a sub-sample of firewood user households from the NLSS survey that collect and use firewood for household energy. Our results are somewhat unexpected. More specifically, contrary to the common belief regarding the efficiency of improved stoves, we find that households with the improved stoves may use more firewood than households with the traditional mud stove or the open-fire stove. This issue, however, needs further investigation to arrive at a definite conclusion since only 2% of households were using improved stoves during the survey year in our data set. One possible explanation of why the improved stove user households may consume more firewood than the traditional open-fire stove or the mud stove users could be the rebound effect as in Zein-Elabdin (1997).[7] For example, when the improved stoves reduce firewood demand in the first place, it would lower the shadow price of firewood. A lower shadow price could in turn prompt households to consume more firewood. An alternative explanation would be that the improved stoves mostly come with attached chimneys that help reduce the amount of smoke in the house. Traditionally, the chimney is not a part of the open-fire or the traditional mud stoves in Nepal. As the smoke level declines due to the chimney (Malla, 2009), household members may feel better in terms of health benefits. Consequently, they may either keep their stove running for longer hours to keep the house warm or cook more frequently requiring more firewood.

Our results indicate that in the presence of a rebound effect and given existing improved stove technology, if we want to reduce demand for firewood the short term solution is to replace open-fire stoves with mud stoves. This switching of stove from open-fire to mud stove would be quite acceptable as about 56% of the households are already using the mud stoves. Such replacement of the open-fire traditional stove with the mud stove does not require any heavy investment since it can be done with simple and locally available technology. While switching from open-fire to mud stove, adding smoke-hood or chimney would help address indoor air pollution problems (Malla, 2009) but it might generate the rebound effect (see Roy, 2000). We wish to reiterate that our intension here is not to ignore negative externalities such as IAP or the GHG emissions and related climate change issues from burning firewood in traditional stoves. Our suggestion is just a short term measure that could potentially reduce firewood demand, and in the long term, the first best option would be to make cleaner fuels or gasifier more accessible to the rural people.

8. Acknowledgements

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[7] For a recent review on the rebound effect on energy use, see Sorrell *et al.* (2009).

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Table 1: Variable Definition and Descriptive Statistics

VARIABLES	Definition	Mean	SD	Min	Max
FIREWOOD	Amount of firewood collection per month (number of bhari)	6.92	4.6	1	40
COLLECTIONTIME	Time to collect one bhari of firewood (hr)	3.67	2.1	0.02	13
OPENFIRESTOVE	1 if household has open-fire stove	0.38	0.49	0	1
MUDSTOVE	1 if household has mud stove	0.56	0.5	0	1
IMPROVEDSTOVE	1 if household has improved stove	0.02	0.15	0	1
KEROSENESTOVE	1 if household uses kerosene or gas stove	0.04	0.19	0	1
HHSIZE	Household size	5.31	2.52	1	32
MALE	1 if household head is male	0.8	0.4	0	1
COWS	Number of cows household has	2	2.39	0	25
BUFFS	Number of buffalos a household has	1	1.28	0	14
COMMFOREST	1 if the household collects firewood from community forest	0.31	0.46	0	1
GOVFOREST	1 if the household collects firewood from government forest	0.31	0.46	0	1
CHILD	1 if the household has a child below 6 years old	0.55	0.50	0	1
FEMALEWAGE	Wage rate (hired female labor) (Rs)	60.6	25.4	9.3	150
REMIT_RECEIVED	1 if the household received remittance	0.33	0.47	0	1
BAHUNCHHETRI	1 if household belongs to Bhramin or Chhetri	0.32	0.46	0	1
EDUCATION	Years of schooling of household head	2.36	3.69	0	17
HILLMOUNTAIN	1 if the household lives in mountain or hilly region	0.61	0.49	0	1

Note: *bhari* is a local unit of firewood measurement, where 1 *bhari* = 30 kgs (average); no. of observations = 2607. This sub-sample includes households who collect and use firewood. We have excluded a few households who collected more than 2 *bhari* of firewood per day as outliers.

Source: Nationally representation household survey data collected by the Central Bureau of Statistics, Nepal, popularly known as the Nepal Living Standard Survey, 2004.

Table 2: Distribution of Household Level Variables by Stove Types (N = 2607)

Variable	Open-fire Stove		Mud Stove		Improved Stove		Gas/Kerosene Stove	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
FIREWOOD	7.67	4.11	6.68	4.97	7.47	3.46	4.16	3.51
COLLECTIONTIME	4.31	1.49	4.18	1.60	4.06	1.48	3.53	1.63
HHSIZE	5.06	2.33	5.59	2.77	4.97	1.53	4.94	1.99
MALE	0.78	0.42	0.81	0.39	0.82	0.39	0.76	0.43
COWS	2.37	2.67	1.78	2.17	1.99	2.39	1.32	1.90
BUFFS	1.24	1.40	0.82	1.18	1.44	1.45	1.69	1.47
CHILD	0.53	0.50	0.57	0.49	0.63	0.49	0.35	0.48
GOVFOREST	0.39	0.49	0.26	0.44	0.32	0.47	0.12	0.33
COMMFOREST	0.34	0.47	0.28	0.45	0.26	0.44	0.37	0.48
REMIT_RECEIVED	0.32	0.47	0.35	0.48	0.35	0.48	0.33	0.47
BAHUNCHHETRI	0.31	0.46	0.27	0.44	0.47	0.5	0.60	0.49
EDUCATION	1.80	3.15	2.29	3.62	4.54	4.90	5.77	5.06
HILL_MOUNTAIN	0.86	0.35	0.37	0.48	0.87	0.34	0.62	0.49

Source: See Table 1

Table 3: Distribution of Variables by Stove Type for the Households Hiring Female Farm Workers (N = 757)

Variable	Open-fire Stove		Mud Stove		Improved Stove		Gas/Kerosene Stove	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
FIREWOOD	8.18	4.44	7.08	5.60	8.06	3.40	4.42	3.54
COLLECTIONTIME	3.45	1.83	3.47	2.30	2.95	1.66	3.47	2.58
HHSIZE	5.00	2.39	6.06	3.12	4.90	1.15	5.2	2.10
MALE	0.78	0.42	0.89	0.31	0.79	0.41	0.77	0.43
COWS	2.46	3.13	2.15	2.18	2.13	2.20	1.39	1.83
BUFFELOWS	1.55	1.38	1.16	1.32	2.13	1.43	2.10	1.69
CHILD	0.49	0.50	0.56	0.50	0.64	0.49	0.33	0.47
GOVFOREST	0.21	0.41	0.17	0.38	0.12	0.34	0.10	0.30
COMMFOREST	0.33	0.47	0.24	0.43	0.32	0.48	0.37	0.49
REMIT_RECEIVED	0.37	0.48	0.35	0.48	0.36	0.49	0.35	0.48
BAHUNCHHETRI	0.46	0.50	0.31	0.46	0.56	0.51	0.60	0.49
EDUCATION	2.81	3.82	3.56	4.25	5.07	5.04	6.65	4.62
HILL_MOUNTAIN	0.88	0.33	0.33	0.47	0.92	0.28	0.60	0.49

Source: See Table 1.

Table 4: Ordinary Least Squared Regression Results

	FIREWOOD		Log(FIREWOOD)	
VARIABLES	Model-I	Model-II	Model-III	Model-IV
MUDSTOVE	-0.845***	-0.846***	-0.150***	-0.150***
	(0.300)	(0.300)	(0.034)	(0.034)
IMPROVEDSTOVE	-0.142	-0.131	0.008	0.010
	(0.594)	(0.596)	(0.073)	(0.073)
KEROSENESTOVE	-3.503***	-3.518***	-0.568***	-0.571***
	(0.523)	(0.522)	(0.079)	(0.079)
COLLECTIONTIME	0.040	0.040	-	-
	(0.065)	(0.065)		
L(COLLECTIONTIME)	-	-	0.054	0.054
			(0.038)	(0.038)
HHSIZE	0.343***	0.351***	0.037***	0.038***
	(0.065)	(0.068)	(0.007)	(0.007)
MALE	0.420*	0.413*	0.055**	0.054*
	(0.216)	(0.218)	(0.027)	(0.028)
COWS	0.123**	0.121**	0.014**	0.014**
	(0.055)	(0.056)	(0.006)	(0.006)
BUFFS	0.475***	0.472***	0.065***	0.064***
	(0.105)	(0.107)	(0.012)	(0.012)
COMMFOREST	0.903**	0.901**	0.154***	0.154***
	(0.389)	(0.390)	(0.043)	(0.043)
GOVFOREST	0.130	0.135	0.049	0.050
	(0.378)	(0.378)	(0.044)	(0.044)
CHILD		-0.097		-0.017
		(0.223)		(0.026)
CONSTANT	4.228***	4.249***	1.563***	1.567***
	(0.418)	(0.427)	(0.058)	(0.059)
Observations	2607	2607	2607	2607
R-squared	0.114	0.114	0.154	0.154

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 5: Two Stage Least Squared Regression Results

VARIABLES	FIREWOOD Model-V	FIREWOOD Model-VI	Log(FIREWOOD) Model-VII	Log(FIREWOOD) Model-VIII
MUDSTOVE	-1.451*	-1.479*	-0.304***	-0.307***
	(0.838)	(0.847)	(0.101)	(0.101)
IMPROVEDSTOVE	10.061*	9.544**	1.089*	1.068**
	(5.387)	(4.210)	(0.618)	(0.477)
KEROSENESTOVE	-1.860	-1.252	-0.270	-0.217
	(2.032)	(1.988)	(0.269)	(0.243)
COLLECTIONTIME	0.276	0.323	-	-
	(0.214)	(0.207)		
COLLECTIONTIME2	-0.022	-0.027	-	-
	(0.019)	(0.018)		
L(COLLECTIONTIME)	-	-	0.061	0.062
			(0.042)	(0.042)
HHSIZE	0.390***	0.411***	0.045***	0.048***
	(0.069)	(0.072)	(0.007)	(0.007)
MALE	0.421*	0.412*	0.059**	0.058**
	(0.223)	(0.223)	(0.029)	(0.029)
COWS	0.109*	0.105*	0.010	0.010
	(0.057)	(0.057)	(0.007)	(0.007)
BUFFS	0.356***	0.343***	0.043***	0.041***
	(0.117)	(0.119)	(0.013)	(0.013)
COMMFOREST	0.844*	0.805*	0.140**	0.138**
	(0.478)	(0.470)	(0.054)	(0.054)
GOVFOREST	-0.049	-0.043	0.024	0.025
	(0.417)	(0.418)	(0.050)	(0.050)
CHILD		-0.226		-0.029
		(0.239)		(0.029)
CONSTANT	3.861***	3.827***	1.606***	1.610***
	(0.680)	(0.692)	(0.075)	(0.075)
Observations	2607	2607	2607	2607
R-squared	0.107	0.108	0.137	0.137

Note: Standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6: OLS and 2SLS Regression Results (Dep Var: Log(*FIREWOOD*) where *COLLECTIONTIME* is replaced with *FEMALEWAGE*)

VARIABLES	OLS Model-IX	2SLS Model-X
MUDSTOVE	-0.179***	-0.264*
	(0.058)	(0.156)
IMPROVEDSTOVE	0.014	0.784
	(0.092)	(0.707)
KEROSENESTOVE	-0.578***	-0.188
	(0.094)	(0.272)
FEMALEWAGE	-0.001	-0.001
	(0.001)	(0.001)
HHSIZE	0.030***	0.036***
	(0.010)	(0.011)
MALE	0.049	0.047
	(0.058)	(0.062)
COWS	0.015	0.016
	(0.010)	(0.010)
BUFFS	0.064***	0.043**
	(0.018)	(0.021)
COMMFOREST	0.217***	0.205***
	(0.105)	(0.012)
GOVFOREST	0.061	0.052
	(0.059)	(0.064)
CHILD	-0.028	-0.032
	(0.051)	(0.056)
CONSTANT	1.765***	1.785***
	(0.100)	(0.141)
Observations	757	757
R-squared	0.137	0.101

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 7: Random Effect Regression (Dep Var: Log(FIREWOOD)

	OLS		2SLS	
VARIABLES	Model-XI	Model-XII	Model-XIII	Model-XIV
MUDSTOVE	-0.042*	-0.042*	-0.251**	-0.262**
	(0.026)	(0.026)	(0.116)	(0.119)
IMPROVEDSTOVE	-0.026	-0.025	0.544	0.373
	(0.065)	(0.065)	(0.483)	(0.363)
KEROSENESTOVE	-0.545***	-0.546***	-0.286	-0.191
	(0.053)	(0.053)	(0.211)	(0.209)
L(COLLECTIONTIME)	0.101***	0.101***	0.117***	0.121***
	(0.030)	(0.030)	(0.030)	(0.031)
HHSIZE	0.044***	0.045***	0.050***	0.052***
	(0.005)	(0.005)	(0.006)	(0.006)
MALE	0.058**	0.057**	0.062***	0.063***
	(0.023)	(0.023)	(0.022)	(0.022)
COWS	0.015***	0.015***	0.011**	0.011**
	(0.005)	(0.005)	(0.005)	(0.005)
BUFFS	0.051***	0.050***	0.034***	0.032***
	(0.008)	(0.009)	(0.009)	(0.010)
COMMFOREST	0.059	0.058	0.034	0.028
	(0.037)	(0.037)	(0.046)	(0.048)
GOVFOREST	-0.021	-0.021	-0.053	-0.053
	(0.036)	(0.036)	(0.045)	(0.046)
CHILD		-0.012		-0.015
		(0.018)		(0.021)
CONSTANT	1.427***	1.429***	1.495***	1.501***
	(0.055)	(0.055)	(0.090)	(0.091)
Observations	2607	2607	2607	2607
Number of PSUs	282	282	282	282

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

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