STOVE ADOPTION AND IMPLICATIONS FOR DEFORESTATION AND LAND DEGRADATION: THE CASE OF ETHIOPIA

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Abstract

In Ethiopia deforestation is a major problem and many peasants have switched from fuel-wood to dung for cooking and heating purposes, thereby damaging the agricultural productivity of cropland. The government has embarked on a two-pronged policy in an effort to stem deforestation and the degradation of agricultural lands: (i) tree planting (afforestation); and (ii) dissemination of more efficient stove technologies. This paper investigates the potential of the strategy of disseminating improved stoves in the rehabilitation of agricultural and forests lands, using a dataset on a cross-section of 200 farm households from the highlands of Tigrai region, northern Ethiopia. Results indicate that farm households in Tigrai region of Ethiopia are willing to adopt new/improved stove innovations if these result in economic savings. Moreover, results suggest a significant positive impact in slowing the degradation of agricultural and forested lands. On a per household basis, we found that adopters collect about 70 kg less wood and about 20 kg less dung each month, which indicates that adoption of improved stoves reduces harvest pressure on local forest stands. In terms of wood alone, assuming an average of 120 metric ton of biomass per ha, we found the potential reduction in deforestation amounts to some 1,200 ha per year, not an inconsequential savings.

Keywords: land degradation; technology adoption; fuel-savings efficiency; stoves; Ethiopia.
JEL classification: Q12; Q16; Q24;

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1. Introduction[4]

Land degradation is a global concern. It affects some two-thirds of worlds' agricultural land resulting in agricultural productivity decline (UNDP, 2002). It results in income loss and food insecurity, threatening livelihoods. It is particularly vexing problem in developing countries because it leads to a poverty trap. Poverty is an ultimate cause of land degradation that, in turn, exacerbates poverty by reducing the quality of the most important resource available for economic development. For example, despite that considerable progress have been made in reducing poverty in some parts of the world – notably in East Asia – over the past couple of decades there are still about 1.4 billion people living on less than US$1.25 a day, and close to 1 billion people suffering from hunger (IFAD, 2010). It is also believed that not less than 70 per cent of the world's very poor people are rural. Among others declining agricultural productivity due to deteriorating natural resource base such as land degradation have contributed to this rural poverty.

In most developing countries, inefficient exploitation of the land reduces the amount of resource rent that can be collected, while lowering available future rents as land resources are degraded over time in a suboptimal fashion (van Kooten and Bulte, 2000). Consequently, increasing poverty combined with lack of property rights to land causes peasants to invest too little in land improvements. A cycle of land degradation occurs because, as forests are mined (depleted), people turn to grasses, crop residues and livestock dung for fuel, which degrades the land further (Pearce and Warford, 1993, p.25). This is certainly true in Ethiopia with deforestation becoming a major problem, many peasants have switched from fuel-wood to dung for cooking and heating purposes, i.e., they substitute dung for fuel-wood in the face of scarcity, thereby damaging the agricultural productivity of cropland. Newcombe (1989) estimated that, by burning some 7.9 million metric tons of dung per year, the reduction in agricultural productivity from lost nutrients associated with manure amounted to some 6 to 9 percent of the country's GNP.

Ethiopia is one of the poorest nations on Earth with an annual purchasing power parity adjusted per capita GDP of about US$ 800 (HDR, 2009). It has a history of civil wars and frequent droughts that have resulted in the starvation of millions. Only about 12 percent

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of the country's surface (i.e., 13.0 million ha of an available land area of 110.4 million ha) are forested (WBISPP, 2004), compared to 40 percent some 100 years ago (EFAP, 1994). Standing timber amounts to some 285 million m^3, or about 22 m^3 per ha. Total biomass in forest ecosystems amounts to 573 million metric tons (t), or 44 t per ha. In 2005, 108.879 million m^3 of timber were harvested for fuel-wood (24.5% more than in 2000) along with 2.982 million m^3 for industrial round-wood (an increase of 21.3% compared to that of 2000), all of which were consumed domestically; harvests of timber for other uses were insignificant in comparison (FAO, 2006). In 2005, timber removals accounted for 39.3% of total growing stock, clearly an unsustainable state of affairs.[5] Between 1990 and 2005, the average annual rate of deforestation was nearly one percent, one of the highest rates in the world.

Review of relevant literature identifies the following outstanding issues. Firstly, whereas substantial growing literature characterizes the important features of adopting agricultural production technologies (Feder *et al.*, 1985; Dadi *et al.*, 2004; Barrett *et al.*, 2004), knowledge about the characteristic of stove adoption is sparse. Secondly, empirical evidences on effectiveness or fuel saving efficiency of the improved stoves, particularly wood stoves, are also extremely scanty and mixed. Thirdly, it is not also clear whether it matters that the stoves are merely saving time or biomass and not money in terms of limiting their successful promotion. Therefore, key questions of interest in here are: How effective is the improved stove being promoted as a remedy to the fuel problem and land degradation? Should it matter that the stoves are merely saving time or biomass and not money? What characterizes stove adoption?

The Ethiopian government has embarked on a two-pronged policy in an effort to stem deforestation and the degradation of agricultural lands – tree planting (afforestation) as a long-term strategy and dissemination of more efficient stove technologies in the short term. The purpose of the current study is to examine the potential of the second strategy, using a unique dataset covering 200 households from the highlands of Tigrai region, northern Ethiopia. Specifically, the objectives are twofold: one, we determine

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[5] Data for Ethiopia pose numerous difficulties (FAO, 2006; 2003; 1997). It seems unreasonable that nearly 40% of total biomass is removed annually, but that is what the 'official' data indicate (www.fao.org/forestry /site/32046/en). Perhaps much of the fuelwood came from trees outside of forests, as FAO defines forests to have 10% or more canopy cover. Alternatively, FAO (2003) data indicated that there were 13.5 million ha of forest in 1995 but only 4.6 million ha in 2000. This could explain high rates of off-take, but it implies an extremely high (perhaps unreasonable) annual deforestation rate of about 19%. Later revisions indicated that forested area stood at 14.4 million ha in 1995, 13.7 million in 2000 and 13.0 million ha in 2005 (FAO, 2006).

what characterizes improved stove adoption; and two, we analyze the impact of disseminating improved stoves in redressing the fuel problem and land degradation. In doing so, our aims are both to determine the propensity to adopt new stoves and to isolate how adoption of improved stoves changes behavior (including, e.g., the frequency with which households prepare hot dishes and the number of cattle they might keep). Because we cannot a priori exclude the possibility of a rebound effect – that use of more efficient stoves actually increases fuel demand rather than reducing it – we need to pay particular attention to the consequences for actual use of the improved stove.[6] In the analysis, we employ a two-step procedure.

In the next section, we review land degradation, deforestation and stoves. Stove R and D in Ethiopia is provided in section 3. Our model of the stove adoption process is provided section 4, while the survey instrument and empirical results are discussed in section 5. The conclusions follow.

2. Land Degradation, Deforestation and Stoves: Review

Despite the fact that considerable progress have been made in reducing poverty in some parts of the world – notably in East Asia – over the past couple of decades there are still about 1.4 billion people living on less than US$1.25 a day, and close to 1 billion people suffering from hunger (IFAD, 2010). It is also believed that not less than 70 per cent of the world's very poor people are rural. Among others declining agricultural productivity due to deteriorating natural resource base such land degradation have contributed to this rural poverty. In this regard, land degradation is a serious global concern. It affects some two-thirds of worlds' agricultural land resulting in agricultural productivity decline (UNDP, 2002). It results in income loss and food insecurity, threatening livelihoods. Of particular concern in this regard is the soil fertility (nutrient) depletion aspect of land degradation. The burning of dung and crop residues which were previously sources of soil humus and fertility for fuel purposes has resulted in a progressive decline in land quality and agricultural productivity. In the context of Ethiopia, this has increased farmers' vulnerability to shocks, food insecurity and poverty (Amsalu, 2006). Scherr

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[6] The new technology might increase wood consumption because, as Wirl (2000) notes, people care only about the services a stove provides (e.g., heat generated) and not about wood use itself. A more efficient stove implies that the same heat is obtained from less wood, so the price of heating services declines and thus households increase their demand for cooking services. This can result in more wood use if the percentage change in services demanded is larger than the percentage change in fuel efficiency associated with the new stove.

(2000) identifies soil erosion, soil fertility (nutrient) depletion, de-vegetation, loss of biodiversity, soil compaction, acidification, and watershed degradation as common problems of land degradation in the densely-populated marginal developing regions. She argues that, among others, improving the productivity of poor people's natural resources assets as the main strategy to simultaneously address poverty and environmental (land) degradation. Scherr further suggests that conditions affecting the adoption of resource-conserving technologies, local endowments as well as local institutions that are supportive to the poor are key factors that determine the interactions between poverty and environment.

In their synthesis of wood-fuels, livelihoods and policy interventions, Arnold et al. (2006) argue that the fuel-wood discourse or crisis has shown a classic pattern of thesis and antithesis over the last few decades. That the use of fuel-wood in developing countries is apparently not growing at the rates assumed in the past. Nonetheless, they also acknowledge that the complex reality in developing countries could seldom be captured in such clear-cut narratives. For example, it might not be the case for Ethiopia, hence the need for location or country specific studies. They argue that responses to fuel-wood shortage are largely conditioned by the household's capacity to access resources such as labor, land, and money as well as other factors such as access to common pool resources availability and price of substitute fuels. That, particularly in rural areas, users switch first to less preferred alternatives (tree species) and then to crop residues, animal dung, and even noxious weeds, as supply of the preferred types of fuel-wood (tree species) diminishes. Such switching or substitution is diverting dung and crop residues from their high value uses in agriculture, such as soil fertility maintenance, and causes ecological (environmental) damages.

Improved stoves have been regarded as technological alternatives to alleviating or mitigating the fuel-wood problem (crisis) particularly since the 'oil price shocks' of the 1970s (Barnes et al., 1993), their greater energy efficiency can reduce fuel shortage and the pressure on local forests. However, knowledge about the characteristic of stove adoption is sparse. Moreover, empirical evidences on effectiveness or fuel saving efficiency of the improved stoves, particularly wood stoves, are also extremely scanty and mixed. For example, Amacher et al. (1996) argued improved stoves significantly decrease fuel-wood consumption and can be an important curb on deforestation. Whereas based on data from three villages (i.e., one remote and two with good market access) in rural Jiangxi Province of China, Chen et al. (2006) found possession of improved stove does not affect fuel-wood consumption in the remote village whereas it increased fuel-wood consumption in the villages with good market access. This was contrary to arguments to promote improved stoves. Arnold et al. (2006) argue that efforts to promote stoves have shown success only in towns, where the stoves are seen as saving money, but not in rural areas, where they are merely saving time or biomass. More importantly, there is also a relatively new and growing interest on the need for improved stoves particularly because of the health impacts of indoor air pollution from the use of biomass fuels (Larson and Rosen, 2002; Sinton et al., 2004; Hutton et al., 2006). Agarwal (1983) summarizes the factors likely to affect the diffusion of wood-stoves into five as: technical aspects related to the method of wood-stove design and development; economic aspects as private financial benefits of investing in an improved wood-stove; infrastructural aspects such as extension and credit provision; cultural aspects including attitude to change; and social structure, i.e., inequalities in social status and the unequal nature of power balance between different classes/casts or sexes, for that matter.

Much of the traditional uses of wood as cooking (plus baking) fuel in most developing countries are also carried out in campfires or stoves where the efficiency of heat use is very low. In these countries wood, dung and crop wastes are typically used with efficiencies not exceeding 9-12 percent (Dunkerley et al. 1981; Gebreegziabher, 2007; Gebreegziabher et al., 2011). It also appears to be clear that among others the use of inefficient stoves also contributed to deforestation (de-vegetation). In fact some further argue that, particularly in urban areas, poorer people are paying higher prices for useable energy than more well off consumers because of the inefficiency of the traditional or bio-fuel using cooking stoves and kerosene lamps, and that inefficient stoves also involve financial burden or inequity (Barnes et al., 2004). Cooke et al (2008) argue that there is little economic investigation of the impact of using an improved stove on actual household fuel-wood demand. They also argue that the evidence on whether household use of an improved stove reduces fuel-wood use is mixed.

The following issues stand out quite apparent from the foregoing reviews. Firstly, that land degradation is a major concern which is undermining the livelihoods of the rural people in the densely populated marginal developing regions like Ethiopia. The diversion of dung and crop residues from their high value uses in agriculture for fuel purposes, because of the shortage of fuel-wood, is the main cause underlying the problem. Thus innovations or resource-conserving technologies and other technological alternatives that improve the productivity of poor people's natural resources assets and simultaneously address poverty and environmental (land) degradation could be thought as a means to deterring the environmental (land) degradation and redressing the problem. Secondly, that, among all others, the use of inefficient stoves also contributed to deforestation (de-vegetation). And, in spite of the scope for reducing the demand for biomass fuels such as fuel-wood and, hence, the pressure on natural resources through improvement in the efficiency of the stoves and despite the attempts in the past to popularize the improved stoves, evidences about the success of these stoves are mixed. Thirdly, there is a knowledge gap about their effectiveness and the potential for further interventions to promote these stoves and the need for such study. Moreover, although outside the scope of this study, more recently, there also appear to be relatively new and growing interest on the need for improved stoves particularly because of the health impacts of indoor air pollution from the use of biomass fuels (Larson and Rosen, 2002; Sinton et al., 2004; Hutton et al., 2006).

3. Stove R and D in Ethiopia

Stove R and D (Research and Development) efforts in Ethiopia began in the 1980s with the World Bank Energy Sector Assessment (World Bank, 1984). Besides identifying short- to long- term options for alleviating the fuel problem/crisis in the country, the assessment also carried out kitchen-lab investigations of fuel-savings efficiency of various stoves. Stove types considered in the investigation and the test results are provided in Appendix Table A.1. As it was quite apparent that injera[7] baking consumes about half of all the household fuel uses, injera cookers received priority. World Bank (1984) found the Tigrai type[8] stove to be twice as efficient as open fire tripods and recommended to be part of the package of cooking efficiency program. Fuel savings of up to 25% was achieved with the Tigrai type stove with no additional fire management.

Two years later, a program of massive diffusion of efficient cooking stoves was designed, with the intention of dissemination of the Tigrai type stoves with little improvement. It was assumed to extend essentially to all rural households within 20 years time and envisaged to allow an overall decrease in energy consumption by about a factor of two (ENEC and CESEN, 1986a). This massive stove diffusion program was also envisaged to

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[7] Injera is a pan-cake like bread typical to Ethiopia

[8] The Tigrai type stove was an indigenous innovation by the local people to the growing fuel scarcity and high fuel prices in the area (ENEC and CESEN, 1986b).

cover essentially all urban households using traditional fuels within the specified time period. Continuing improvement in stove designs was also expected in the years beyond the planning horizon, that is, beyond 2005 in order to allow a further decrease in the demand for traditional fuels of about 50 percent. The importance of an efficient extension service was recognized to support the diffusion of the efficient stoves.[9]

However, these stoves had no chimney, which is detrimental to family health as cooking areas fill with smoke. Hence, a second generation stove arose as the partially clay-enclosed stove was subsequently improved upon by the introduction of a three-stove model that included a chimney and an even lower grate height and was entirely enclosed (RTPC, 1998). The three-stove model consists of a baking oven, a stove for heating water and sauces, and a grain-roasting compartment. Thus, with little additional effort, the three stove Tigrai variant yielded more fuel savings.

The more recent -third generation -re-design of the Tigrai variant drops the separate compartments of the three-stove model, replacing it with a double-walled stove with a baffle that permits smoke (and heat) to recycle before it escapes out of the chimney – essentially a combined-heat stove, known as a Tehesh[10] stove. As a result, further fuel savings of 22 percent can now be realized compared to the Tigrai variants that have only a single wall. The stove design and efficiency tests including kitchen lab and field-testing were undertaken by the RTPC (Rural Technology Promotion Center) in Mekelle. Six stove designs of various attributes were considered in the testing with Tehesh stove identified having the highest efficiency as compared to all others (Gebretsadik et al., 1997). Then after pilot dissemination program was initiated for Tehesh stove during the 1998/99 in eight districts of the Tigrai region (BoANR, 1998).

The fourth generation development of stove named Mirte[11] is a pumice-cement stove. It has the advantage of being easily assembled and need not be fixed. Initial laboratory tests of this stove demonstrated 35 percent fuel savings efficiency compared to the open fire tripod. Recent refinement on Mirte stove achieved further increases in

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[9] The extension service was regarded essential for providing assistance in the use of the stoves in new households and monitor the activities to determine the degree of appropriateness and utilization as well as the physical conditions of the stove (ENEC and CESEN, 1986a).

[10] This latest R and D effort is peculiar and sole initiative of the provincial government of Tigrai in collaboration with GTZ (German Technical Cooperation) (Tadesse, 1996).

[11] Cooking efficiency and new fuels marketing project, under the Ethiopian Energy Study and Research Center (EESRC) in Addis Ababa, developed this stove (Bess & Kenna, 1994).

efficiency and reached 50 percent fuel savings compared to open fire tripod (Bess & Kenna, 1994), which perhaps might give it a smaller margin over Tehesh.

Dissemination of improved stove in Tigrai also started before 1991. However, it was in the post-1991 period that it was more strengthened. For instance, a total of 77,563 improved stoves, i.e., three-stove model, were disseminated or built in rural Tigrai during the years 1991/92 - 1996/97 (BoANR, 1997).[12] However, except for all these attempts, it is not yet clear whether the stoves being disseminated actually have the desired level of efficiency in terms of fuel saving and whether there is a scope for further improvements in fuel efficiency, therefore, the need for empirical investigation. Moreover, it is not yet clear what factors determine the adoption of these fuel saving stoves.

As could be clear from Table A.2 in the Appendices, the fact that the vast majority of biomass fuel is used for baking and cooking as opposed to lighting and heating justifies the R and D effort on injera cookers (stoves). It is also worth noting that in the diffusion process peasants do not purchase these stoves rather each person is taught how to build an improved stove based on information or advice provided by an extension agent. Advice/instruction about improved stove construction involved standard stove dimensions including grate height, gate area, etc. Moreover, since improved stoves are constructed with the supervision of extension/home agent, quality is assumed to be guaranteed. Hutton et al. (2006) argued that some households might continue to use their traditional stove for certain tasks. But, in our case, adoption requires that households dismantle their old stoves, so that one type of stove is in use at any given time. Moreover, there is generally inadequate room in a household's living quarters for more than one stove.

4. Conceptual Model

The household utility function could be envisaged to be driven by diverse set of factors or characteristics including availability of food (own produced or market purchased), convenience, health, status, etc. However, it is also clear that not all or just few of these factors are amenable to be captured quantitatively. Therefore, to establish how the

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[12] This job of improved stove dissemination was held under the Rural Women's Desk in the Bureau of Agriculture and Natural Resources (BoANR). The responsibility for technical design and stove development was under the Rural Technology Promotion Center (RTPC) within the BoANR (Gebretsadik et al., 1997).

adoption of an improved stove is expected to affect household welfare, we postulate the following household utility function:

$$U_i = U(c_i, cf_i, tscw_i, tscd_i, an_i, z_i), \qquad \textbf{(1)}$$

where ci denotes household i's consumption during the period under consideration, cfi is the frequency with which the household cooks (number of times per month), tscwi is the time spent by the household collecting woody biomass for fuel purposes, tscdi is the time spent collecting dung for fuel, and ani is the number of farm animals the household owns. Cooking frequency is likely to be driven by the dietary habit/type of dish a household is used to consume, availability of and ability to purchase different food[13] items as grains, etc. Household time use certainly involves time for fuel collection, cooking, childcare, cleaning, for different types of income generating activities, and consumption (leisure). However, emphasis has been placed to time spent collecting fuel particularly wood and dung for the intention in here is to assess how the adoption of an improved stove affects household welfare. Finally, zi is a vector of household characteristics that includes the number of household members, household income, and so on.

Consumption and number of farm animals are expected to contribute positively to household welfare (the latter also because cattle are a status symbol), whereas the amount of time spent collecting fuel (either woody biomass or dung) is expected to affect household utility negatively. We distinguish between times spent on the two types of fuels because the dis-utilities associated with collecting the two types of fuel may well differ. Finally, the effect on household welfare of cooking frequency is ambiguous. On the one hand, higher cooking frequency may reflect more flexibility (being able to prepare warm dishes whenever one desires), but, on the other hand, higher cooking frequencies may simply be the result of limited stove capacity. If the time spent cooking is valued negatively, an increase in cooking frequency may well be welfare decreasing.

When deciding whether or not to adopt an improved stove, the household will try to infer how the use of this technology is likely to affect family well being. The improved stove may affect the frequency with which the household cooks, and it may affect both

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[13] It could be that they buy grains from the market and in the end cook it at home. However, it has to be noted that buying prepared/cooked meals so often is not in the lifestyle of the community in question.

the total time the household spends collecting fuel (both woody biomass and dung) (Barnes et al., 1993), and the relative amount of time spent collecting either fuel type. Let I be an indicator variable with value 1 if the household uses an improved stove, and 0 otherwise. Then, the probability of household i using an improved stove (I=1) is determined as follows:

$$P(I=1) = f(\Delta x_i, y_i, s_i, l_i), \quad \text{with } x_i = (cf_i, tscw_i, tscd_i, an_i), \qquad \textbf{(2)}$$

where Δxi=xi(I=0)–xi(I=1) reflects the amount of variable x saved when household i replaces its old stove by an improved version. Further, yi is exogenous income of household, si denotes household size (number of household members), and li denotes other household characteristics including location or agro-ecology conditions of the village where the household resides (upper or middle highlands, vis-à-vis lower highlands) (Barrett et al., 2004).

Unfortunately, we do not have any direct information about the changes in xi at the household level– cooking frequency (Δcfi), the time spent collecting dung (Δtscdi) or woody biomass (Δtscwi), and number of livestock (Δani). This means that we have to develop an estimation strategy that allows us to calculate the (expected) changes per household associated with the use of the new stove. The key assumption here is that there are no systematic differences between households that have adopted the new stove and those that have not; they are drawn from essentially the same distribution.14 That means controlling for all (quantifiable) household characteristics, such as exogenous income, family size and composition, etc., adopting households are not inherently more prone to using larger quantities of wood and dung, for example, than non-adopting households. If that is the case, it is the combination of household characteristics that determines adoption behaviour, and not so much one or two specific characteristics. One theoretical explanation suggested in line with the fact that adoption is not instantaneous, i.e., some households adopt an innovation while others do not, is that some are wealthier and can afford the technology whereas others cannot (Verspagen, 2005). However, in this study we postulate that it is not a single factor/characteristic that determines adoption, rather it is a combination of characteristics.

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[14] Statistically speaking, in order for the two sub-samples to be comparable and to carry on the necessary computations/estimation, the two sub-samples must be drawn from the same population or distribution. Therefore, this key assumption is guaranteeing or saying that the two sub-samples are essentially drawn from the same distribution.

On the basis of this assumption, (expected) changes in cooking frequency, time spent collecting dung, time spent collecting woody biomass and livestock numbers can be inferred. We briefly explain the steps that are used to implement this in the current study. First, we consider the validity of the key assumption that all households are drawn from essentially the same distribution by testing whether adopters and non-adopters differ systematically with respect to any of the key characteristics for which we have information. We obtain support for our assumption if we are unable to reject the hypothesis that there are no systematic differences in the household characteristics of adopters and non-adopters.

Next, if our assumption is not violated, we proceed to estimate how the levels of cooking frequency (cfi), the time spent collecting dung (tscdi) or woody biomass (tscwi), and the livestock (ani) vary across households, using household characteristics as explanatory variables:

$$x\text{i} = g\text{x}(y\text{i}, s\text{i}, l\text{i}, z\text{i}), \ \forall x\text{i} = (cf\text{i}, tscd\text{i}, tscw\text{i}, an\text{i}), \qquad \textbf{(3)}$$

where zi is again a vector of other regression-specific household characteristics and superscript x indicates that the specification may differ for each of the four variables of interest.

Endogeneity and simultaneity are clearly important issues that need to be addressed. Some variables might be expected to be endogenous, given that all dependent variables are explanatory variables in at least one other regression. Thus the system of regression equations in (3) must be estimated using two-stage least squares (2SLS) regression specification, with all truly exogenous variables (e.g., location, household characteristics) as instrumental variables.

We estimate (3) for the sample of households that have adopted the improved stove, as well as for the sample of households that have not adopted the improved stove. Thus, we obtain two sets of coefficients on each of the (regression-specific) explanatory variables. The differences between these coefficients for each explanatory variable are then used to calculate the predicted savings on the dependent variables associated with the adoption of an improved stove. We denote these predicted savings by $\Delta\hat{x}_i$. In turn, these predicted savings are then used as regressors in equation (2), together with household characteristics such as income (yi), family size (si) and location or agro-ecology (li).

This two-step procedure considerably mitigates the endogeneity problem of determining a household’s propensity to adopt a new stove, as well as the main factors affecting that propensity, and the household-specific benefits the stove is expected to provide; especially given the households of both samples are drawn from the same distribution. If the households in the two samples do not differ systematically with respect to essential household characteristics, we can infer that all households are potential adopters of new stoves. However, the household-specific combination of characteristics may be such that some households are observed to adopt a new stove while others do not. That is, whether or not they discard their traditional stove depends on the household-specific savings a new stove provides, and these are calculated by multiplying the differences in the slope coefficients by the associated explanatory variables.

5. Estimation Results and Discussion

Our data are from a survey of 200 households in Tigrai region, northern Ethiopia, collected during the year 2000. This was the only dataset involving observations on improved stoves that we could find in Ethiopia. Two-stage sampling was used to select the sample households. Four households were chosen at random from each of 50 tabias – the smallest administrative unit in the region – selected at random from a total of 600 tabias in the province. The (local) tabia administration is responsible for maintaining household lists from which the households targeted for interview were chosen.

Both quantitative and qualitative data were collected on the household’s production (collection) and consumption of various biomass fuel types; demographic characteristics of the household include age, sex and literacy level of head of household and household size. Family resource endowments include total land ‘leased’, cultivated area, number of trees, livestock holdings and type of stove used by the household. Also available from the survey are village level factors, including agro-ecological conditions or altitude range, and distance traveled (time spent) to collect different fuels.

Data on cooking/baking frequency of a household was weighted for respective end use share in the total household fuel, using Table A.2 in the Appendices. Information on the different fuel types collected by the household was obtained in local units of measurement, but in a way that facilitated conversion to metric units and minimized errors.[15] The survey instrument was translated into the local language (Tigrigna) and administered to the participating households using trained enumerators. Table 1 provides summary statistics of the variables considered in the analysis.

Table 1: Summary statistics of variables considered in the analysis (n=200)

Variable	Mean	Std. dev.	Min.	Max
Family size	5	2	1	12
Adult males in household	1	1	0	5
Adult females in household	1	1	1	4
Age of household head	48	13	23	85
Education of head of household (years of schooling)	0.92	1.47	0	7
Sex of head				
Female	21%			
Male	79%			
Exogenous income (ETB/month)	0.35	2.86	0	25
Number of cattle	4	3	0	14
Land area (hectares)	0.834	0.496	0	2.5
Cooking frequency (monthly)	52.989	19.670	12.742	210.315
Wood price/shadow (Eth Birr/hour)	1.483	7.285	0	18.376
Dung price/shadow (Eth Birr/hour)	0.266	0.849	0	3.618
Wood consumption (kg/month)	117.875	86.310	0	420
Dung consumption (kg/month)	90.034	94.570	0	628.5
Kerosene consumption (lit/month)	1.745	6.890	0.11	97.68
Households involved in tree planting	93%			
Households not involved in tree planting	7%			
Total no. of trees per household (all trees)	74	172	0	1834
Time collecting wood and/or dung (minutes/month)	1850.367	2032.632	0	11817.5
Use wood from own trees (=1; 0 otherwise)				
Yes (% of households involved))	18			
No	82			
Use improved stove (=1; or, 0 otherwise)				
Yes (% of households involved))	40.5			
No	59.5			
Location or agro-ecology (% of households involved)				
Upper highland	18			
Middle highland	50			
Lower highland (reference)	32			

[a] Eth Birr is the Ethiopian currency, $1 USD = 13.49 Eth Birr as of 12 March 2010.

Before proceeding, it is necessary to check whether we can reject the hypothesis that the households in the two samples (those who have and those who have not adopted an

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[15] The enumerators or data collectors were provided with weighing balances upon departure for field work. The respondents are kindly requested to display a sample of the quantity of wool or dung collected in local units. Then, measurement of the actual quantities (in metric units) of the local units of wood and dung displayed is taken using a weighing balance.

improved stove) are drawn from the same distribution. We employ Mann-Whitney U-tests to validate and check whether the two samples differ in terms of these key characteristics. [16,17] The results do not allow us to reject the hypothesis that the two samples do not differ with respect to any of the individual household characteristics. Although this is not a definitive proof, it does give credence to our claim that it is the household-specific combination of characteristics that determines whether a household adopts a new stove.

Before proceeding, it would also be worthwhile to provide the reader the insights as to how improved stove adoption is related to our variables of interest cooking frequency, time spent collecting wood, time spent collecting dung, and cattle holding. As it could be clear from Appendix Table A.3, adoption or use of improved stove is negatively related to cooking frequency, time spent collecting wood as well time spent collecting dung; whereas it is positively related to number of cattle or cattle holding of household.

a. The First-Stage Regression Results

The impact of using an improved as opposed to a traditional stove was investigated by examining the four-equation regression model, Equation (3), for the adopting and non-adopting households separately. We do not impose any restrictions that slope and/or intercept coefficients have to be identical across the two samples. Because of endogeneity[18] and simultaneity considerations, the four equations were estimated as a system of equations using two-stage least squares (2SLS) regression[19] with the following instrumental variables: location (middle and upper highlands), family size and composition (i.e., number of adult females), land size, and the dummy variable 'use wood from own trees'. The regression results are provided in Table 2.

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[16] The Mann-Whitney U-test is a non-parametric test. First, all observations in each of the adopters and non-adopters sub-samples are ranked from highest to lowest with respect to the variable of interest. The two series are then merged. Upon going down the merged series, if the observations roughly alternate between the two sub-samples, then the Mann-Whiney U-test fails to reject the assumption that observations are drawn from the same population. Alternatively, if observations from the top of the list all come from one sub-sample while those at the bottom from the other, the test rejects the null hypothesis of a common population (Harnett, 1982).

[17] For completeness we also provide the test results (p-values) of the two-sided Mann-Whitney U-tests with respect to whether the two samples differ in terms of these key characteristics in Table A4 in the appendix.

[18] Hausman test of endogeneity (see Verbeek, 2004) was carried but only correct one, i.e., results of 2SLS with instrumental variables are reported for sake of space.

[19] Selection bias is another important issue that needs to be taken care of besides endogeneity (simultaneity). Therefore, IMR (inverse Mills ratio) was computed by running a probit regression of the standard stove adoption equation and then included as a regressor in the systems (2SLS) to check for the selection bias. However, the IMR turned insignificant in both cases, i.e., non-adopters and adopters, which prove that there hardly exists anything to worry about the selection bias. Hence, results of 2SLS estimation without IMR have been reported.

Table 2: 2SLS regression results for households that have adopted (n=81) and have not adopted (n=119) improved stove.[a]

	Adopter				Non adopter			
Explanatory variable	**(1) Cooking frequency**	**(2) Number of cattle**	**(3) Time collecting wood**	**(4) Time collecting dung**	**(5) Cooking frequency**	**(6) Number of cattle**	**(7) Time collecting wood**	**(8) Time collecting dung**
Exogenous income (Birr/month)	0.045[b]	0.009***	-1.794	1.271	0.032[b]	0.007***	0.199	-0.033
	(0.028)	(0.004)	(2.979)	(1.136)	(0.020)	(0.003)	(1.923)	(0.734)
Family size (number)	8.931**		105.793	-19.004	8.645**		159.500*	13.760
	(3.820)		(106.906)	(45.156)	(3.646)		(89.110)	(23.283)
Family size squared	-0.764**				-0.585*			
	(0.314)				(0.332)			
Number of adult females (number)			260.180	224.481**			640.906**	160.493**
			(333.536)	(98.594)			(294.599)	(73.494)
Land size (*tsmdi*)[c]		1.898***	-680.773	-64.241		1.479***	-57.725	-19.381
		(0.632)	(494.877)	(257.873)		(0.508)	(391.651)	(158.236)
Number of cattle (number of heads)				6.338				16.139
				(129.570)				(90.968)
Time collecting wood and/or dung (minutes/month)	-0.004				-0.005**			
	(0.003)				(0.003)			
Wood from own trees (=1; else 0)			-251.022				707.369	
			(488.509)				(498.363)	
Middle highland (=1; 0 otherwise)		0.483	-934.825**	229.598**		-0.508	160.026	209.414*
		(0.570)	(443.828)	(113.641)		(0.574)	(434.613)	(116.893)
Upper highland (=1; 0 otherwise)		-0.509	-1115.262**	83.074		-0.725	-480.649	144.842
		(0.731)	(567.849)	(164.182)		(0.740)	(550.395)	(151.095)
Constant	29.066***	0.876	1838.313***	-200.398	34.255***	1.531**	-123.845	-120.192
	(9.601)	(0.752)	(685.459)	(175.073)	(10.473)	(0.733)	(685.972)	(211.326)
R^2	0.0603	0.2723	0.0974	0.1959	0.0710	0.2223	0.1527	0.0723

[a] Standard errors in parentheses: ***, ** and * indicate significance at the 1%, 5% and 10% levels (or better), respectively.

[b] p≤0.11.

[c] *tsmdi* is local unit for land area -1 *tsmdi*=0.25 hectare

Most of the variables in the two cooking frequency equations (columns 1 & 5, Table 2) are statistically significant at the 10% level or better. Households cook more often the larger household income, the larger the family (albeit at a decreasing rate), and the less time they allocate to fuel collection, which is probably indicative of a readily available (nearby) source of fuel. Moreover, adopters cook less frequently than non-adopters, probably because of the convenience provided by the improved stove to combine baking and other cooking activities.

Only exogenous income and the area of land 'controlled' by the household are found to be statistically significant variables explaining cattle ownership in both the non-adopter and adopter equations (column 2 and 6, Table 2). As expected, both variables contribute positively to the number of cattle a household will own. It would appear that households own cattle as a form of wealth, especially because private landownership is not permitted. Somewhat surprisingly, the household's location[20] or agro-ecology is not found to affect the number of cattle it keeps.

The most important factors explaining the amount of time allocated to collecting wood in the non-adopters equation (column 7, Table 2) are family size (larger families need to collect more wood) and the number of adult females in the household (as adult females traditionally engage in fuel collection). Location or agro-ecology was found unimportant. In contrast, neither family size nor number of adult females is statistically significant in the adopters equation (column 3), but households located in the middle or upper highlands spend less time on wood collection, with coefficients for these location dummy variables statistically significant at the 5% level or better. Families that have adopted the improved stove spend less time collecting wood as such stoves are more efficient in their use of wood. Interestingly, exogenous income, land area, and whether or not one uses wood from trees located on the homestead are not found to be important determinants of time spent collecting fuel-wood.

Similar to the fuel-wood equations, the number of adult females and the household's location (in the middle highlands) provide a statistically significant explanation of household time spent on dung collection (columns 4 and 8, Table 2). However, unlike the case for fuel-wood, number of adult females is statistically significant in the adopters

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[20] Results are in reference/relation to lower highland. Many studies have used dummy variables to capture the effect of location or village agro-ecological conditions (see, for example, Pender et al., 2006).

as well as non-adopters equation. And only the middle highlands dummy variable is statistically significant, but then in both equations. Surprisingly, while dung collection time would be expected to be inversely related to the number of cattle owned by the household, it turned out statistically insignificant and positive (both in the non-adopter and adopter equations). Exogenous income has the expected positive sign, but is only statistically significant in the adopters' equation. Also family size and the size of the land area are found to be statistically insignificant determinants of time spent collecting dung.

1. Derived demand equations for fuel-wood and dung for both adopting and non-adopting households were also estimated using seemingly unrelated (SUR) regression with double-logarithmic functional forms. The double logarithmic function was preferred to a linear one as it provided a better fit to the data. Free collection accounts for the majority of the fuels consumed in the study area. The households considered use family labor in fuel collection. Though fuel-wood is traded in the towns at the vicinity of the study sites, a lesser proportion of the households were involved in fuel-wood buying. Almost all of the sample households were not involved in buying dung. Moreover, hiring labor for fuel collection is not common practice. Hence, it was clear that hired labor and family labor are not perfect substitutes and market wage rate cannot be taken as an appropriate measure of the opportunity cost of family labor used in fuel collection. Therefore, under such imperfect/missing market conditions 'virtual (shadow) prices are appropriate measures (Singh et al., 1986) and we used these prices in our analysis.[21] The shadow prices were computed from the dataset following Jacoby (1993), Thornton (1994), Mekonnen (1999), Kohlin and Parks (2001) and Amacher et al. (2004). Results are provided in Table 3.

As expected, own (shadow) prices calculated from the survey are statistically significant explanations of fuel-wood and dung use and have the correct negative signs in each of the four equations. The prices of competing goods (e.g., shadow price of dung in the case of fuel-wood) have the correct sign in all four equations, but are statistically significant only in the non-adopter equations. Using data from Amhara region of Ethiopia, Mekonnen (1999) find that wood and dung are complementary. However, our results suggest that they are substitutes. Hagos et al. (2003) also find that an increase in

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[21] Note the prices (shadow) are the outcomes of households' optimization in the classic case of the non-separable household model (Singh et al., 1986).

shadow price of dung is negatively related with fuel-wood consumption, indicating that the two goods are complements rather than substitutes. Amacher et al. (1993) also find that crop residues and fuel-wood appear to be substitutes in one district whereas they appear to be complements in the other/adjacent district. As in the time spent collecting dung equations (Table 2), location variables are statistically significant in the dung demand function, while location is generally not important in determining the demand for fuel-wood (with the possible exception of middle highlands in the case of non-adopters). Finally, the estimated coefficients for income by non-adopting households and family size by adopting households have the expected signs and are statistically significant in the fuel-wood demand equations, while the same is true for number of cattle in the dung demand equation for non adopters. These results are subsequently used, along with those of Table 2, to determine savings from adopting the new stove technology.

The predicted savings in cooking frequency, time spent collecting fuel-wood, time spent collecting dung and livestock numbers are provided in Table 4. As indicated above, these are obtained by multiplying the differences in the estimated coefficients with the household-specific values of the explanatory variables. We find that the use of an improved stove is correlated with lower cooking frequencies, less time spent collecting fuel (both wood and dung), and increased cattle ownership. As indicated by the negative savings in Table 4, cattle holding of household increases by about 0.6 animals on average probably because cattle are kept as a store of wealth and as a status symbol. The latter result also indicates that, at the margin, any change that affects the value of cattle to the household affects livestock holdings. Thus, even though cattle might be kept because they also provide dung for cooking and now less dung is required per household, each family will strive to increase their cattle holding.

Table 3: SUR regression results for derived demand functions for fuel-wood and dung for non-adopters and adopting households, Double-Logarithmic functional form[a]

Explanatory variable	Fuel-wood		Dung	
	Non adopter	Adopter	Non adopter	Adopter
Exogenous income	0.7707***	0.3172	-0.1926	0.4932
	(0.1859)	(0.2878)	(0.2261)	(0.5412)
Family size	0.2728	0.5344**	-0.0525	-0.2444
	(0.2761)	(0.2389)	(0.3363)	(0.4480)
Number of cattle	0.0377	-0.1985	0.5877***	-0.0646
	(0.1456)	(0.1997)	(0.1773)	(0.3728)
Price of wood (shadow)	-0.4747***	-0.2253**	0.2500***	0.2713
	(0.0742)	(0.1061)	(0.0914)	(0.2214)
Price of dung (shadow)	0.1792**	0.0540	-0.5773***	-0.6165***
	(0.0920)	(0.0689)	(0.1134)	(0.1292)
Use wood from own trees			0.1123	0.3273
(=1; 0 otherwise)			(0.2739)	(0.4298)
Middle highland (=1; 0	-0.4401*	-0.1328	1.6389***	1.1179***
otherwise)	(0.2321)	(0.2163)	(0.2817)	(0.4071)
Upper highland (=1; 0	-0.3301	-0.3367	1.8821***	1.6004***
otherwise)	(0.3257)	(0.3113)	(0.3952)	(0.5914)
Constant	-0.1791	2.0809	3.1435***	3.4904
	(0.8990)	(1.5088)	(1.0908)	(2.9052)
Number of observations	54	39	54	39
LR χ^2(df)	62.13(7)***	11.52(7)^{b}	96.07(8)***	49.03(8)***
R^2	0.5350	0.2280	0.6392	0.5457

[a] Standard errors are provided in parenthesis: ***, ** and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively.

[b] p-value=0.1175.

Table 4: Predicted time and other savings from adopting an improved stove, standard error (in parentheses) and t-tests of difference from zero

Item	Cooking frequency	Number of cattle	Time collecting wood	Time collecting dung	Fuel-wood (kg/mo)[a]	Dung (kg/mo)[a]
Predicted savings	4.697	-0.599	472.665	40.840	68.278	19.899
$(\Delta\hat{x}_i)$	(0.708)	(0.142)	(66.171)	(18.950)	(22.575)	(11.371)
t-values	6.63	-4.22	7.14	2.15	3.02	1.75

[a] Predicted saving obtained from derived demand functions estimated in Table 3.

The savings in terms of woody biomass and dung are also provided in Table 4. The estimated savings were obtained by comparing the predicted demands for adopters and non adopters of the improved stove technology. The results are interesting because they suggest that adoption of the new stove reduces harvesting pressure on local forest stands. Not only do the times spent collecting dung and wood go down, but, as a result, less wood and dung are used for cooking purposes. On a per household basis, we calculate adopters collect 68.278 kg less wood each month and about 19.899 kg less dung each month. These results were found to be significant at the 1% and 10% levels, respectively. However, results also suggest that adoption of an improved stove could have mixed environmental benefits. Grazing pressure on communal lands is likely to go up, as the number of cattle *increases* by an average of 0.6 per household.

5.2 The Adoption of Improved Cooking Stoves in Tigrai

We can now determine the factors that are likely to affect the adoption decision (Equation 2). Apart from the predicted savings in cooking frequencies, cattle holdings and the amount of time allocated to collecting fuel-wood or dung, we hypothesize that the decision to adopt an improved cooking stove also depends on other household characteristics, including household income, size and location. However, it is important to note that unlike other adoption studies, for example, variables such as the literacy level or education of head, attitude, etc. are not included because the argument in here is that it is the utility gains, i.e., expected savings, in terms of cooking frequency, time spent collecting fuels, and cattle number that ultimately matters whether or not the household adopts the stove. Availability of credit was also considered unimportant as the innovation/technology in question is self made and does not involve any cash outlay. The results of the probit regression are presented in Table 5.

The results are revealing. The savings in cooking frequency, time spent collecting wood and cattle numbers are all statistically significant factors explaining adoption. The time saved collecting dung is not found to be an important factor in the adoption decision, even though one would expect time spent collecting dung to decline as a result of adopting the new stove (since new stoves rely on wood only). We also find that, having controlled for the impact of household characteristics on the households' savings, their direct impact on the decision to build a new stove is negligible. Only households located in the upper highlands are found to be less likely to adopt new stoves.

Table 5: Probit regression of the adoption of an improved cooking stove in Tigrai, Ethiopia (n=200)

Explanatory variable	Estimated coefficient[a]	Standard error
Saving in cooking frequency	0.0160*	0.0092
Saving in cattle numbers	1.5606**	0.7587
Saving in time collecting fuel-wood	0.0009*	0.0005
Saving in time collecting dung	0.0057	0.0040
Household income	0.0167**	0.0076
Household income squared	-0.00002[b]	0.00001
Family size	-0.3482	0.2188
Middle highlands (=1; otherwise 0)	-1.2333***	0.4395
Upper highland (=1; otherwise 0)	-1.8988**	0.7852
Constant	-1.3884	0.9657
LR $\chi^2(9)$	17.59**	
Pseudo R^2	0.0652	

[a] ***, ** and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively.

[b] p-value = 0.108

6. Conclusions

Improved stoves have been regarded as technological alternative to alleviating or mitigating the fuel-wood problem (crisis) particularly since the ‘oil price shocks’ of the 1970s, their greater energy efficiency can overcome fuel shortage. However, knowledge about the characteristic of stove adoption is sparse whereas substantial growing literature characterizes the important features of adopting agricultural production technologies. By and large, empirical evidences on effectiveness or fuel saving efficiency of the improved stoves, particularly wood stoves, are also extremely scanty and mixed. Using a dataset on cross-section of 200 farm households from the highlands of Tigrai region, northern Ethiopia, this paper investigates the role of disseminating improved stoves in redressing fuel problem and land degradation as well as determines the factors that affect the stove adoption decision. Key questions involved are: How effective is the improved stove being promoted as a remedy to the fuel problem and land degradation? Should it matter that the stoves are merely saving time or biomass and not money? What characterizes stove adoption?

The results in this paper indicate that peasants in Tigrai region, Ethiopia, are willing to adopt new technologies if these result in economic savings. Barnes et al. (1993) argue that improved stove programs have been most successful when targeted to specific areas where fuel-wood prices or collection time are high. In this study, we found that the adoption of a more energy efficient or improved stove is proportional to the economic savings in fuel collection time, cooking frequency and cattle required for everyday purposes. Our research also suggests that there may be a significant positive impact in slowing the degradation of agricultural and forested lands. Unlike Arnold et al. (2006) findings this paper indicates that it shouldn't matter the stoves are merely saving time or biomass. In fact, results suggest that expected savings, in terms of cooking frequency and time spent collecting wood, would also provide sufficient incentive to induce stove adoption decision. We find that the use of an improved stove is correlated with lower cooking frequencies, less time spent collecting fuel (both wood and dung), and increased cattle ownership. The latter result is suggestive of the fact that cattle in the study area are kept as a store of wealth and as a status symbol. This is also quite intuitive in the sense that in traditional societies like the community in question, irrespective of where it (the savings) comes from, it is kept in the form of cattle or livestock whenever there is savings.

Based on our findings, improved stoves appear to reduce land degradation in three ways: (i) By switching to an improved stove as opposed to the traditional one, less dung is collected as fuel so more manure is available to benefit the soil. (ii) Adoption of improved stoves results in less wood used as fuel, ceteris paribus, thus reducing deforestation pressure. As a result, more wood is available for others (non adopters and adopters), which implies less dung and crop residues will be used for fuel. (iii) Finally, through its effect on time savings, stove adoption results in less time spent collecting fuel-wood and dung, and in less time spent cooking. If labor markets also function fairly well, this would mean that more time is available for off-farm work, leading to less time spent in agricultural and forestry activities. That, in turn, would imply reduced pressure on forests and agricultural land.

Lastly, the importance of new stoves can be determined from the results in this paper. For example, consider a setting/region where there are some 600,000 rural households. Let the probability that a household will adopt a new stove be 0.2884, implying that some 173,000 households are likely to adopt the more efficient stove technology. Given that each adopting household collects on average 68.278 kg less fuel-wood and 19.899

kg less dung per month, total potential savings could amount to approximately 141,745 t fuel-wood and 41,289.564 t dung per year. Clearly, these estimates are based on potential, which assumes that all dung not collected would have been used in agriculture, and that all fuel-wood savings come from forested areas. Nonetheless, in terms of wood alone, assuming an average of 120 t biomass per ha (much higher than the current average), the potential reduction in deforestation amounts to nearly 1,200 ha per year, not an inconsequential savings. Furthermore, assuming that there are almost 1 million ha of cropland in the setting/region in question, the dung saving translates into about 0.05 of an additional ton of organic matter per hectare per year, again a substantial benefit.

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Appendices

Table A.1: Stove efficiency test results of '*Injera*' cookers

Energy Form	*Injera* Cooker Type	Cooking Time per Injera	Energy per Injera	Cooker Efficiency (PHV)[a]
		(Minutes)	(MJ)	(%)
Biomass Fuels				
Twigs, leaves: sticks (1:3)	Open fire with '*mitad*' on stones, height 13 cm	5.6	12.3	4.3
Twigs, leaves: sticks (1:4)	Filipini stove: molded clay design fully enclosed with '*mitad*' inset and chimney, height 15 cm	13.1	11.1	4.8
Wood:	Tigrai stove: enclosed by clay walls with many small gaps in walls exhaust, height 14 cm	4.2	5.3	10.0
Twigs, leaves: sticks (1:3)	Experimental: like Tigrai with chimney, passive damper, height 12 cm	5.0	9.2	5.7
Electricity	Sample of models commonly marketed in Addis Ababa Mock-up of Aluminum *injera* cooker	3.0-4.0 not available	0.9	60 80

Note: [a] PHV= percentage of heat utilized

Source: UNDP/World Bank [1984].

Table A.2: End-use share of fuels used in Tigrai by location, 1993–1994 (%)

Location	End Uses				
	Baking	Cooking	Lighting	Beverage prep.	Other
Mekelle	43.49	54.47	0.91	0.77	0.36
Large towns	52.06	44.81	2.31	0.72	0.07
Medium towns	54.34	43.11	1.70	0.83	0.03
Small towns	53.53	42.35	3.38	0.68	0.06
Rural areas	60.54	35.47	2.44	1.55	0.00

Source: EESRC (1995).

Table A.3: OLS regression results for cooking frequency, cattle ownership and fuel collection, all households (n=200)[a]

Explanatory variable	(1) Cooking frequency	(2) Number of cattle	(3) Time collecting wood	(4) Time collecting dung
Household income	0.035**	0.007***	-0.038	0.486
	(0.014)	(0.002)	(1.558)	(0.369)
Use improved stove (=1; otherwise 0)	-5.010*	0.560[b]	-434.193*	-49.506
	(2.688)	(0.352)	(261.850)	(61.470)
Family size	8.616***		135.532**	8.763
	(2.424)		(67.028)	(15.722)
Family size squared	-0.700***			
	(0.209)			
Number of adult females			452.220**	174.567***
			(216.346)	(50.484)
Land size		1.594***	-309.073	19.807
		(0.391)	(298.642)	(70.761)
Number of cattle				-20.459*
				(12.284)
Time spent collecting wood and/or dung	-0.0019*** (0.0006)			
Use wood from own trees (=1; otherwise 0)			113.979 (341.379)	
Middle highlands (=1; otherwise 0)		-0.121 (0.405)	-238.408 (305.644)	206.415*** (71.002)
Upper highland (=1; otherwise 0)		-0.567 (524)	-854.286** (390.763)	101.077 (91.284)
Constant	30.786***	1.097**	888.781*	-87.624
	(6.674)	(0.561)	(497.884)	(116.691)
R^2	0.138***	0.235***	0.096***	0.141***

[a] Standard errors are provided in parentheses: *** indicates statistical significance at the 1% level, ** at the 5% level, and * significant at the 10% level.

[b] Statistically significant at 11.3%.

Table A.4: Means and standard deviations of 5 key household characteristics for households with and without an improved stove, and p-values of the two-sided Mann-Whitney U test.

	Household income (Birr/month)[a]	**Family size (number)**	**Number of cattle (number of heads)**	**Land size (*tsmdi*)**[b]	**Middle highlands**[c]	**Upper highlands**[d]
Traditional	145.954	5.395	3.370	3.423	0.538	0.193
stove	(105.578)	(2.210)	(2.864)	(2.095)	(0.501)	(0.396)
Improved	131.2821	5.432	3.765	3.207	0.444	0.160
stove	(74.259)	(2.127)	(2.481)	(1.809)	(0.500)	(0.369)
p-values	0.743	0.893	0.155	0.956	0.196	0.555

[a] Birr is Ethiopian currency currently 1US $ = 12.534 Birr

[b] *tsmdi* is local unit for land area -1 *tsmdi*=0.25 hectare

[c] middle highland with altitude range between 2000 to 2500 meters above sea level

[d] upper highland with an altitude range above 2500 meters above sea level