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Land degradation in Ethiopia: What do stoves have to do with it?

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December 2005

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Land degradation in Ethiopia: What do stoves have to do with it?

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Abstract

Land degradation is a particularly vexing problem in developing countries; as forests are depleted, crop residues and dung are used for fuel, which degrades cropland. In Ethiopia, the government encourages tree planting and adoption of energy efficient stove technologies to mitigate land degradation. We use data from 200 households in Tigrai, Ethiopia to examine the adoption of new stove technologies. Adoption is an economic decision, related to savings in time spent collecting fuel and cooking, and cattle required for everyday purposes. Results indicate adopters of efficient stoves reduce respective wood and dung use by 68 and 316 kg per month.

Key words: land degradation; technology adoption; Africa; Ethiopia.

Acknowledgements: The authors thank the Agricultural Economics and Rural Policy Group at Wageningen University, the Netherlands, REPA Research Unit at the University of Victoria, Canada, and the Canada Research Chairs program for research support.

1. BACKGROUND

Land degradation is a 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. 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, people turn to grasses, crop residues and livestock dung for fuel, which deteriorates the land further (Pearce and Warford 1993, p.25).

This is certainly true in Ethiopia where deforestation is a major problem, and many peasants have switched from fuelwood to dung for cooking and heating purposes, 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 $700. It has a history of civil wars and frequent droughts that have resulted in the starvation of millions. Only 4.2 percent of the country's surface (or 4.6 million ha of an available land area of 110.3 million ha) are forested, compared to 40 percent some 100 years ago (Hawando 2004). Standing timber amounts to some 259 million m^3, or about 56 m^3 per ha, indicating a preponderance of dry rather than wet tropical forest ecosystem.

Total biomass in forest ecosystems amounts to 363 million metric tons (t) or 79 t per ha. In 2000, 87.471 million m^3 of timber were harvested for fuelwood along with 2.459 million m^3 for industrial roundwood, all of which were consumed domestically; harvests of timber for other uses were insignificant in comparison (FAO 2003). Between 1990 and 2000, the average annual rate of deforestation was 0.8 percent, one of the highest in the world.

The Ethiopian government has embarked on a two-pronged policy in an effort to stem deforestation and the degradation of agricultural lands – tree planting or afforestation as a long-term strategy and dissemination of more efficient food stove technologies in the short term. The purpose of the current study is to examine the potential of the second strategy. Using a unique data set covering 200 households, we analyze the impact of the use of a more energy efficient (improved) food stove on household behavior. Our purposes are both to determine the propensity to adopt new stoves and to isolate how adoption of improved stoves changes behavior (including 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.

In the analysis, we use a two-step procedure reminiscent of hedonic pricing. In the first step, we employ a regression model to predict changes in cooking frequencies, time spent collecting fuelwood and dung, and cattle numbers associated with the adoption of the improved technology. These estimates are then used as regressors in the second step, namely, the estimation of the adoption equation.

Our data were collected in Tigrai province, which is located in the most northern part of Ethiopia, along the border with Eritrea. In this region, the area of forested land is well below the national average, constituting slightly more than 1% of the province's 5.156 million ha total land mass. Deforestation in the region has resulted in excessive soil erosion and a fuel wood shortage, or fuel crisis. The fuel crisis has exacerbated the impact of soil erosion as peasants have substituted crop residues and dung for fuelwood, leading to a reduction in nutrients available for crop and forage production.

In the next section, we describe the study region in greater detail, while the survey instrument is discussed in section 3. Our model of the stove adoption process is provided in the fourth section, followed by the empirical results are provided in section 5. The conclusions follow.

2. LAND USE IN TIGRAI PROVINCE

The economy of the study region is agricultural, accounting for 57 percent of regional GDP, with crop and livestock production accounting for 95 percent of agricultural activity. The region is mountainous, with moderate (700-1200 mm) rainfall in the southern and western part and in a very few parts of eastern Tigrai; remaining areas receive 600 mm or less of rainfall as a decreasing function of increasing elevation from the low-lying west to the eastern part of the province. Inter-year variability in precipitation (coefficient of variation of 30%) is a distinguishing characteristic of the region. The rainfall to potential evapo-transpiration ratio is generally less than 0.65 (except in the far western part), which indicates that the region consists principally of dry sub-humid to arid ecosystems. The agricultural economy is principally a crop-livestock economy, with much of the area constituting arid or semi-arid rangelands and croplands that provide subsistence levels of grains for humans and livestock during periods when range forage is limited.[1] Land use is indicated in Table 1, while livestock numbers and forage needs are provided in Table 2.

<Insert Tables 1 and 2 about here>

The population of Tigrai is about 3.6 million of which 84% is rural and dependent on agriculture. Rural people do not have access to electricity while kerosene and other fuels are beyond the means of most households. Peasant farmers and pastoralists do not own their own land, because as Article 40 of the 1994 Constitution of Ethiopia (which came into effect 22 August 1995) states: "The right to ownership of rural and urban land is exclusively vested in the state ... and shall not be subject to sale or exchange". The Constitution guarantees rights of access to land for peasants and pastoralists, and specifies the right of individuals to improvements they make on land, including the right to bequeath, transfer, remove or claim compensation for such improvements as the right expires. Yet, land is public property and land reallocations have not occurred in Tigrai since 1991 as sales are officially prohibited, except for areas where public irrigation or other major infrastructural investments have been built. While the tenure holder (the peasant/pastoralist) has the right to continue to lease the land, use hired labor on the land, and even to rent and bequest the lease, land cannot be sold or exchanged nor leased (rented) for an indefinite period. Nor is there any guarantee that the state will not take away 'rights' to land at some future date. In essence, then, the rights to land

[1] The growing season for range vegetation is somewhere between 160 and 250 days.

constitute dead capital, as it cannot be used as collateral for loans (De Soto 2000).[2]

Households do not have property rights with respect to land, but they are entitled to harvest the products they have planted. These titles are informal in the sense that common values and norms prevent others from harvesting the land, but claims can also be enforced via the court system. The same is true of shrubs and trees located on land that is recognized as having been leased by a particular farmer, and trees/shrubs and dung 'dropped' by their own livestock on the homestead. In short, any biomass on homesteads is considered to belong to the person living on the property. However, crop residues, leaves and/or dung left on leased fields are open access property, available to anyone who chooses to collect this biomass for fuel.[3] Also the forests that do exist are considered an open access resource, with peasants harvesting wood for fuel. These arrangements are expected to affect the time spent collecting dung and fuelwood.

The fact that forests are considered an open access resource has contributed to the high rate of deforestation and is exacerbated by population growth that is forecast to average 1.96% per year as Ethiopia's population expands from 64.5 million in 2001 to 171.0 million in 2050 (The Economist 2003). As noted, the only realistic alternatives to firewood are the use of dung and crop residues, but this has an adverse effect on agricultural productivity. To counter the use of crop residues and dung and the degradation of treed areas, the government promotes the adoption of improved cooking stoves that make more efficient use of wood fiber as one strategy to reduce deforestation. The reason is that the vast majority of biomass fuel is

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[2] Interestingly, to counter feelings of tenure insecurity among farmers, issuance of land certificates has been undertaken since 1998. De Soto characterizes such practices as typical of the extra-legal sector. Only formal recognition of title by the state, the ability to transfer title and a constitutional guarantee (upheld by the courts) that land rights cannot be summarily revoked can provide the institutional framework needed for development.

[3] Not surprisingly, farmers collect as much of the crop residues as possible at the time of harvest.

used for baking and cooking as opposed to lighting and heating, as indicated in Table 3.

<Insert Table 3 about here>

Cooking stoves that are partially enclosed by a clay wall, locally known as the '*Tigrai* type', were found to be twice as efficient as open fire tripods for cooking. However, these stoves had no chimney, which is detrimental to family health as cooking areas fill with smoke. 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 as it was entirely enclosed. Thus, with little additional effort, the 'three stove' *Tigrai* variant yielded fuel savings of 25 percent (World Bank 1984). The 'three-stove model' consists of a baking oven, a stove for heating water and sauces, and a grain-roasting compartment.

The more recent re-design of the *Tigrai* variant drops the separate compartments of the 'three-stove' model, replacing it with a double-walled stove that permits smoke (and heat) to circulate between the two walls before it escapes out of the chimney – essentially a combined-heat stove, known as a '*Tehesh*' 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. Although the survey considered both the 'three-stove' and 'double-walled' stove versions, nearly all of the adopters (78 out of 81) were found to use the 'three stove' model, because the *Tehesh* stove was not yet available at the time the survey was conducted.

It is worth noting that peasants do not purchase these stoves and there is no one representative model of each type. Rather, each person is taught how to build an improved stove based on information or advice provided by an extension agent. Adoption of a new stove is generally accompanied by the dismantling of the old stove, so that only one type of stove is in use at any given time. The reason is that there is generally inadequate room in a household's living quarters for multiple stoves. By adopting a more efficient ('improved') stove, a household can reduce the amount of dung and wood it uses for cooking. To determine the impact of the adoption of improved stoves, we develop a regression model and estimate it using the results from a survey of 200 peasant farmers conducted during 2003-2004. We also project potential fuel savings from this adoption decision.

3. THEORETICAL MODEL

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

(1) $U_i = U(c_i, cf_i, tswc_i, tscd_i, an_i, z_i)$,

where c_i denotes household *i*'s consumption during the period under consideration, cf_i is the frequency with which the household cooks (number of times per week), $tswc_i$ is the time spent by the household collecting woody biomass for fuel purposes, $tscd_i$ is the time spent collecting dung for fuel, and an_i is the number of farm animals the household owns. Finally, z_i 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 because cattle are a status symbol), whereas the amount of time spent collecting fuel (either dung or woody biomass) is expected to affect household utility negatively. We distinguish between times spent on the two types of fuels, because the disutilities 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, higher cooking frequencies may simply be the result of limited stove capacity. If the time spent cooking is valued negatively, a higher cooking frequency may then be welfare decreasing.

When deciding whether or not to adopt an improved stove, the household will try to infer how the use of that technology is likely to affect family well being. The improved stove may affect the frequency with which the household will cook, and it may affect both the total time the household spends collecting fuel (both dung and wood biomass), 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:

(2) $P(I=1) = f(\Delta x_i, y_i, s_i, l_i)$, with $x_i = (cf_i, tswc_i, tscd_i, an_i)$,

where Δx_i reflects the amount of variable *x saved* when household *i* replaces its old stove by an improved version, that is, $\Delta x_i = x_i(I=0) - x_i(I=1)$. Furthermore, y_i is household income, s_i denotes household size (as measured by number of household members), and l_i denotes other household characteristics including location (upper or middle highlands, or lowlands).

Having established the factors that are likely to affect the adoption probability, we now determine the changes in terms of cooking frequency (Δcf_i), the time spent collecting dung ($\Delta tscd_i$) or woody biomass ($\Delta tswc_i$), and number of livestock (Δan_i). We first determine how these variables vary across households, using household characteristics as explanatory variables:

(3) $x_i = g^x(y_i, s_i, l_i, z_i),\ \forall\, x_i = (cf_i, tswc_i, tscd_i, an_i)$,

where z_i 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.

We estimate these regressions for the sample of households that have adopted the improved stove, as well as for the sample of those who have not. Thus, we obtain two sets of coefficients on each of the (regression-specific) set of explanatory variables. The difference between these coefficients for each explanatory variable can be 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 household income (y_i), family size (s_i) and location (l_i).

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 if 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. Whether or not they discard their traditional stove depends on the household-specific savings a new stove provides, and this is calculated by multiplying the differences between the slope coefficients with the associated explanatory variables.

4. ESTIMATION RESULTS

Our data are from a survey of 200 households in Tigrai province, Ethiopia. Two-stage sampling was used to select the sample households. First 50 *tabias* – the smallest administrative unit in the region – were randomly selected from a total of 600 available *tabias*, and then a random sample of 200 households was selected from these *tabias*. 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 the household head and household size. Family resource endowments include total land 'leased', cultivated area, number of trees, livestock holdings and type of stove used by household. Also obtained from the survey were village level factors, including agro-ecological conditions or altitude range and distance traveled (time spent) to collect different fuels.

Data on cooking/baking frequencies of household was weighted for respective end use share in the total household fuel using Table 3. Information on the different fuel types collected/consumed by the household was collected in local units of measurement, but in a way that facilitated conversion to metric units and minimized errors. Considerations were also made to capture seasonal patterns of fuel availability and use. The survey was translated into the local language (Tigrigna) and administered to the participating households using trained enumerators.

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 improved stove) are drawn from the same distribution. Table 4 provides the mean values of the key household characteristics for the samples of households that have and have not adopted the improved stove. The table also provides the p-values of the two-sided Mann-

Whitney U-tests with respect to whether the two samples differ in terms of these key characteristics. The results clearly indicate that the two samples do not differ with respect to any of the individual household characteristics; it is the household-specific combination of characteristics that determines whether a household adopts a new stove.[4]

<Insert Table 4 about here>

4.1 The first-stage regression results

The impact of using an improved as opposed to a traditional stove is first investigated by examining the four regression equations (equation 3) for all households, where a dummy regressor is used to represent whether or not the household has adopted the new stove type. From these results, we obtain insights into whether the use of an improved stove is associated with more or less time spent collecting fuel, with higher or lower cooking frequencies, and with numbers of livestock. The regression results are provided in Table 5, while the separate regression results for households that have and have not adopted the improved stove, equation (3) proper, are provided in the Appendix. In Table 5, the cooking frequency and number of cattle equations are estimated using OLS and provided in the first two columns. The two equations representing the times spent collecting wood and dung are provided in the second to last and last columns of the table and are estimated as a system of equations using seemingly unrelated regression (SUR), because the two activities compete for the same scarce household

[4] If households that have adopted spent considerably more time on fuel collection, cooked more often, and had more livestock than those households that did not adopt the improved technology (even when controlling for income, location etc.), we systematically underestimate the benefits of adopting the new stove for those households who ended up using it – as derived from estimating (3) and subtracting. Therefore, if the resulting savings in cooking time, times spent collecting fuel or cattle are found to be significant in regression (2), we can infer that they are indeed important factors determining adoption behavior.

time so that the error terms are likely correlated.

<Insert Table 5 about here>

All of the variables in the cooking frequency equation 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 have to allocate to fuel collection, which is probably indicative of a readily available (nearby) source of fuel. Further, whereas the sign on the use of an improved stove is theoretically ambiguous (see above), the regression results indicate that the household's cooking frequency is negatively correlated with the use of improved stoves.

Only household income and the area of land 'controlled' by the household are found to be statistically significant variables explaining cattle ownership (column 2, Table 5). 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. The use of an improved stove is not found to affect cattle ownership, although the estimated coefficient is positive and has a p-value of 0.113. Somewhat surprisingly, the household's location is not found to affect the number of cattle it keeps.

The most important factors explaining the amount of time allocated to collecting wood (column 3) are family size, the number of adult females in the household (as it is the adult females who traditionally engage in fuel collection), and whether the household is located in the upper highlands, all of which are statistically significant at the 5% level or better. As expected, larger families need to collect more wood as they use more, while those with more females will also spend more time collecting wood. Further, those families that have adopted the improved stove spend less time collecting wood as such stoves are more efficient in their use of wood. Interestingly, household 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 fuelwood.

As in the fuelwood equation, 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 (column 4, Table 5). In addition, as expected, dung collection time is inversely related to the number of cattle owned by the household. Household income and the size of the land area are found to be statistically insignificant determinants of time spent collecting dung, as was the case in the fuelwood collection regression. However, neither family size nor the adoption of the new stove type turned out to be statistically significant, the latter probably because the new stoves operated only with wood not dung.

The regression results in Table 5 enable us to compare the impacts of using an improved stove on the four variables of interest. Whereas these regressions assume identical slopes on the explanatory variables across the equations, allowing only the intercepts to differ between adopters and non-adopters of the improved cooking stoves, we calculate the predicted values of x based on the same specification as in Table 4, but then estimated for the samples of adopters and non-adopters separately. By estimating separate regressions for adopters and non-adopters, we do not impose any restrictions that slope and/or intercept coefficients have to be identical across the two samples. These regression results are provided in Appendix Table A.1. The predicted savings on each of the four variables of interest, as obtained by multiplying the difference of the coefficients with the household-specific values of the explanatory variables, are provided in Table 6. In line with the results obtained in Table 5 (where only intercepts were permitted to differ), we find that the use of an improved stove is correlated with lower cooking frequencies, less time spent on collecting fuel (both wood and dung), and greater cattle ownership.

<Insert Table 6 about here>

These results are interesting as they suggest that adoption of an improved stove has mixed environmental consequences. Time spent collecting dung and wood goes down, suggesting that less wood and dung are being used for cooking purposes. We can estimate the extent of wood and dung savings by assuming a Cobb-Douglas (double logarithmic) functional form for the derived demand equations for fuelwood and dung. (The double logarithmic functional form was preferred to a linear function as it provided a better fit to the data.) The demand equations are estimated as a system using SUR, with the results reported in Appendix Table A.2. By comparing the predicted demands for adopters and non-adopters, it was possible to calculate predicted savings in wood and dung from using the new stove technology.

The results of these calculations indicate that the pressure on local forest stands declines. On a per household basis, we predict that adopters will collect 68.278 kg less wood each month, while more dung in the form of manure becomes available as 316.005 kg less dung is collected each month (Table 6). (These results are found to be significant at the 1% and 10% levels, respectively.) However, grazing pressure on communal lands is likely to go up, as the number of cattle *increases* by an average of 0.5 per household.

4.2 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 on cooking frequencies, cattle holdings and the amount of time allocated to collecting fuelwood 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. The results of the probit regression are presented in Table 7.

<Insert Table 7 about here>

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. 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.

5. DISCUSSION

The results in this paper indicate that peasants in Tigrai province, Ethiopia, are willing to adopt new technologies if these result in economic savings. In this case study, we found that the adoption of a more energy efficient or improved stove is proportional to economic savings in fuel collection, 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.

Based on our findings, improved stoves appear to reduce land degradation in three ways: (1) 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. (2) 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. (3) Finally, through its effect on time savings, stove adoption results less time spent collecting fuelwood and dung and less time spent cooking. Since labor markets function fairly well in Tigrai, this means more time is available for off-farm work, leading to less time spent in agricultural and forestry activities. This implies, in turn, reduced pressure on forests and land.

Lastly, the importance of new stoves can be determined from the results in this paper. There are some 600,000 rural households in Tigrai province. The probability that a household will adopt a new stove is 0.2884, implying that some 173,000 households are likely to adopt the more efficient technology. Given that each adopting household collects 68.278 kg less fuelwood and 316 kg less dung per month, total potential savings amount to approximately 141,745 t wood and 656,016 t dung per year. In terms of wood alone, assuming an average of 79 t of biomass per ha, the potential reduction in deforestation amounts to some 1,794 ha per year, not an inconsequential savings. Given there are almost 1 million ha of cropland in Tigrai, the dung saving translates into about two-thirds of an additional ton of organic matter per hectare, again a substantial benefit.

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Table 1: Distribution of Land Use in Tigrai Province

Land Use	Millions ha	% of the Region
Cultivated for crop production	1.300	25.2
Potential forest land (not current cover)	0.436	8.5
Grazing and browsing	1.459	28.3
Not utilizable	1.495	29.0
Other	0.464	9.0
Total	**5.156**	**100.0**

Source: Haileselassie (2000, p.46)

Table 2: Livestock Numbers and Tropical Livestock Unit (TLU) Equivalence, Tigrai Province

Livestock species	Number (millions)	Conversion factor to TLU	Total TLU (millions)	% of total TLU
Cattle	3.041	0.7	2.128	83.6
Sheep	0.935	0.1	0.093	3.7
Goats	1.466	0.1	0.147	5.7
Horses	0.005	0.8	0.004	0.2
Donkeys	0.303	0.5	0.152	6.0
Mules	0.010	0.7	0.007	0.3
Camels	0.014	1.0	0.014	0.5
Subtotal	5.774		2.543	100
Poultry	2.259	0.01	0.023	

Table 3: 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: Ethiopian Energy Study and Research Center (1995, p.13)

Table 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	Family size	Number of cattle	Land size	Middle highlands	Upper highlands
Traditional stove	145.954 (105.578)	5.395 (2.210)	3.370 (2.864)	3.423 (2.095)	0.538 (0.501)	0.193 (0.396)
Improved stove	131.2821 (74.259)	5.432 (2.127)	3.765 (2.481)	3.207 (1.809)	0.444 (0.500)	0.160 (0.369)
p-values	0.743	0.893	0.155	0.956	0.196	0.555

Table 5: 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 6: Predicted Savings and Standard Deviations (in parentheses) of the Dependent Variables[a]

Item	Cooking frequency	Number of cattle	Time collecting wood	Time collecting dung	Wood (kg/mo)	Dung (kg/mo)
Predicted savings ($\Delta\hat{x}_i$)	4.697 (4.447)	-0.599 (0.544)	472.665 (780.507)	40.840 (121.219)	68.278 (307.054)	316.005 (2396.066)
t-values	14.94	15.57	8.24	4.48	3.02	1.75

[a] Predicted saving using double-logaritmic derived demand functions (see Appendix Table A.2).

Table 7: 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	0.0455*	0.0261
Saving in cattle numbers	1.4678*	0.7587
Saving in time collecting fuelwood	0.0005*	0.0003
Saving in time collecting dung	0.0022	0.0025
Household income	0.0048	0.0044
Family size	-0.1100	0.0950
Middle highlands (=1; otherwise 0)	0.4395	0.6400
Upper highland (=1; otherwise 0)	-0.6433**	0.3137
Constant	-0.1179	0.4770
LR $\chi^2(8)$	12.98[b]	
Pseudo R^2	0.0481	

[a] * indicates statistically significant at the 10% level or better and ** at the 5% level or better.
[b] p-value = 0.1127.

APPENDIX

Table A.1: Separate Regression Results for Households that have and have not adopted the Improved Stove[a]

Explanatory variable	Cooking frequency		Number of cattle		Time collecting wood		Time collecting dung	
	Non adopter	Adopter	Non adopter	Adopter	Non adopter	Adopter	Non adopter	Adopter
Household income	0.0311^{b}	0.0497**	0.0067***	0.0094***	0.3352	-1.8239	0.1815	1.5237**
	(0.0191)	(0.0249)	(0.0024)	(0.0036)	(1.8568)	(2.8274)	(0.4493)	(0.6731)
Family size	8.9924***	6.9971**			162.5762*	104.8483	16.9618	-8.3696
	(3.4866)	(3.1611)			(86.0578)	(101.4605)	(20.5700)	(24.3486)
Family size squared	-0.6843**	-0.6284**						
	(0.3062)	(0.2667)						
Number of adult females					644.9527**	256.1144	154.6545**	207.6565***
					(284.5214)	(316.4669)	(68.0662)	(74.2383)
Land size			1.4790***	1.8984***	-96.5178	-672.1929	28.7505	1.2958
			(0.5079)	(0.6315)	(378.0729)	(469.293)	(90.8188)	(113.8876)
Number of cattle							-18.0548	-30.5552^{b}
							(15.8945)	(19.3091)
Time spent collecting wood and/or dung	-0.0026***	-0.0007						
	(0.0009)	(0.0009)						
Use wood from own trees (=1; 0 otherwise)					493.5738	-199.9014		
					(476.9087)	(445.0512)		
Middle highland (=1; 0 otherwise)			-0.5077	0.4826	186.4519	-938.3727**	190.0719*	241.6705***
			(0.5743)	(0.5701)	(419.6731)	(421.2437)	(99.7802)	(98.6758)
Upper highland (=1; 0 otherwise)			-0.7248	-0.5087	-498.6556	-1109.264**	118.5169	56.3064
			(0.7398)	(0.7307)	(531.5443)	(538.8608)	(127.3503)	(126.4923)
Constant	30.1558***	28.2008***	1.5311**	0.8764	-107.1846	1836.819***	-71.5548	-182.4077
	(9.3862)	(8.7023)	(0.7335)	(0.7522)	(662.4935)	(650.7171)	(159.8002)	(152.7832)
R-squared	0.1442***	0.1211**	0.2227***	0.2718***	0.1506***	0.0982	0.1084**	0.2213***

[a] Standard errors in parentheses: ***, ** and * indicate significance at the 1%, 5% and 10% levels (or better), respectively. [b] p≤0.11.

Table A.2: SUR Regression Results for Derived Demand Functions for Fuelwood and Dung for Non-adopters and Adopting Households, Dougle-Logaritmic Functional Form[a]

	Wood		Dung	
Explanatory variable	Non adopter	Adopter	Non adopter	Adopter
Household 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)	(0.4479)
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**	0.2499***	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			0.1123	0.3273
trees (=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	5.6284***	3.4904
	(0.8990)	(1.5088)	(1.0908)	(2.9052)
R-squared	0.5350***	0.2280[b]	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.