LAND DEGRADATION IN ETHIOPIA:

WHAT DO STOVES HAVE TO DO WITH IT?

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Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12 -18, 2006

ABSTRACT

In Ethiopia 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. The Ethiopian government has embarked on a two-pronged policy in an effort to stem deforestation and the degradation of agricultural lands: (i) tree planting or afforestation; (ii) dissemination of more efficient stove technologies. The motivation in here is, therefore, to examine the potential of the strategy of disseminating improved stoves in the rehabilitation of agricultural and forests lands. For empirical analysis we used a dataset on cross-section of 200 farm households from the highlands of Tigrai, northern Ethiopia. We used a two-step procedure reminiscent of hedonic pricing. Results in this paper indicate that farm households in Tigrai/ 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 will collect 68.3 kg less wood each month, while more dung in the form of manure becomes available as 19.899 kg less dung is collected each month. In terms of wood alone, assuming an average of 79 t of biomass per ha, we found the potential reduction in deforestation amounts to some 1,794 ha per year, not an inconsequential savings.

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

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1. BACKGROUND

In most developing countries, inefficient exploitation of the land reduces the amount of resource rent that can be collected, while lowering available future resource rents as land resources degrade over time in a suboptimal fashion (van Kooten and Bulte 2000). 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. In Tigrai province, for example, dung rose from about 10% of total household fuel consumption in the 1980s to about 50 percent by the year 1999 (see Tables 1 and 2). Such burning of dung and crop residues which were sources of soil humus and fertility has brought about a progressive decline in land quality and agricultural productivity.[1]

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 and dissemination of more efficient stove technologies. The motivation is to examine the

[1] 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.

potential of the second strategy. Using a unique data set covering 200 households, we analyze the impact of the use of improved 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.

The paper is organized as follows. In the next section, we review stove R&D in Ethiopia. Our model of the stove adoption process is provided in section 3, while the survey instrument & empirical results is discussed in section 4. The conclusions follow.

2. STOVE R&D IN ETHIOPIA

Stove R&D 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 in the country, the assessment carried out kitchen-lab investigations of fuel-savings efficiency of various stoves. The '*Tigrai* type' stove was found to be twice as efficient as open fire tripods and was 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.[2]

Then, a program of massive diffusion of efficient cooking stoves was designed, with the intention of disseminating of the "Tigrai type" stoves with little improvement (ENEC & CESEN, 1986b).[3] 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 gate height and was

[2] The "*Tigrai* type" stove was an indigenous innovation by the local people to the growing fuel scarcity and high fuel prices in the area.
[3] The importance of an efficient extension service was recognized to support the diffusion of the efficient stoves.

entirely enclosed. The ‘three-stove model’ consists of a baking ‘oven’, a stove for heating water and sauces, and a grain-roasting compartment.

Dissemination of improved stoves in Tigrai 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 in rural Tigrai during the years 1991/92 - 1996/97 (BoANR, 1997).

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*’ 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 (Gebre et al, 1997).[4] Then after "pilot" dissemination program was launched for "*Tehesh*" stove during the 1998/99 in eight districts of the Tigrai (BoANR, 1998).

The fourth generation/development of stove named ‘*mirte*’[5] is a pumice-cement stove. It has the advantage of being easily assembled and need not be fixed. Incremental refinements on ‘*mirte*’ stove achieved further increases in efficiency and reached 50 percent fuel savings compared to open fire tripod (Bess & Kenna, 1994).

3. THEORETICAL MODEL

To establish how the adoption of an improved stove is expected to affect

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

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

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, $tswc_i$ is the time spent by the household collecting woody biomass, $tscd_i$ is the time spent collecting dung, an_i is the number of farm animals the household owns, and z_i is a vector of household characteristics.

Consumption and number of farm animals are expected to contribute positively to household welfare; 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. 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 $x_i = (cf_i, tswc_i, tscd_i, an_i)$,

with Δx_i the amount of variable x *saved* when household i replaces its old stove by an improved version, i.e., $\Delta x_i = x_i(I=0) - x_i(I=1)$. Furthermore, y_i is household income, s_i denotes household size, and l_i denotes other household characteristics including location.

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:

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

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 that 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,* $\Delta \hat{x}_i$, on the dependent variables associated with the adoption of an improved stove. 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. 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.

4. ESTIMATION RESULTS

Our data are from a survey of 200 households in Tigrai province, Ethiopia. Data were collected on the household's production and consumption of various biomass fuel types; demographic characteristics of the household and family resource endowments including type of stove used by household. Also obtained from the survey were village level factors, including agro-ecological conditions and 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. 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. Therefore, findings pertain to the '*three stove*' model.

Before proceeding, it is necessary to check whether we can reject the hypothesis that the households in the two samples 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.[6]

4.1 The first-stage regression results

Table 5 provides the first–stage regression results. The cooking frequency and number of cattle equations (the first two columns in Table 5) are estimated using OLS. The other two equations representing the times spent collecting wood and dung are estimated as a system of equations using seemingly unrelated regression (SUR).

Findings reveal that 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. 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 land area 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. 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.

Family size, number of adult females in the household, and whether the household is located in the upper highlands are the most important factors explaining the amount of time allocated to collecting wood (column 3). As expected, larger families need to collect

[6] If households that have adopted spent considerably more time on fuel collection, cooked more often, and had more livestock than those that did not adopt the new stove (even 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. 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.

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.

As in the fuelwood equation, the number of adult females and the household's location 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. 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. Household income and the size of the land area are found to be statistically insignificant determinants of time spent collecting dung.

We calculate the predicted values of *x* based on the same specification as in Table 5, but then estimated for the samples of adopters and non-adopters separately. By doing so we do not impose any restrictions that slope and/or intercept coefficients have to be identical across the two samples. 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.

We estimate the extent of wood and dung savings by assuming a double logarithmic functional form for the derived demand equations for fuelwood and dung, using SUR. 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. These results are interesting as they suggest that adoption of an improved stove has mixed environmental consequences. Suggest 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 19.899 kg less dung is collected each month (Table 6). Nevertheless, 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 hypothesized that the decision to adopt an improved stove also depends on other household characteristics, including household income, size and location. The results of the probit regression are presented in Table 7.

Results are reveal that 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 findings also suggests that there may be a significant positive impact in slowing the degradation of agricultural and forested lands.

Improved stoves appear to reduce land degradation in three ways: (1) By switching to an improved stove and discarding 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, which implies less dung and crop residues will be used for fuel. (3) 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 19.899 kg less dung per month, total potential savings amount to approximately 141,745 t wood and 41,289.564 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.

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Table 1 Consumption of a representative household in domestic uses in 1999 by fuel type, for rural Tigrai (in mega joules)

Fuel type	Average consumption	Percent of total
Woody biomass	38,267.2	48.65
Animal dung	37,469.6	47.63
Crop residues	2,047.5	2.6
Charcoal	858.0	1.1
Oil products	17.3	0.02
Total	78,659.6	100.0

Source: Gebreegziabher (2001)

Table 2 Comparison of share in total fuel consumption of various sources for Tigrai (%)

Year	ENEC & CESEN 1986a Tigrai (overall)	EESRC 1995	
		Urban	Rural
Fuel wood and tree residues	82.40	49.0	65.8
Animal Dung	10.60	2.6	18.1
Agri Residues	6.00	2.2	8.6
Charcoal	0.90	40.9	6.6
Oil products	0.05	4.4	0.9
Electricity	0.05	0.8	0.0
Total	100.0	99.9	100.0

Sources: ENEC & CESEN (1986a) and EESRC (1995)

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: EESRC (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	-238.408	206.415***
		(0.405)	(305.644)	(71.002)
Upper highland (=1; otherwise 0)		-0.567	-854.286**	101.077
		(524)	(390.763)	(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 provided in parentheses: ***, ** and *indicate statistical significance at 1%, 5% and 10% level.

[b] Statistically significant at 11.3%.

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

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)	19.899 (242.124)
t-values	14.94	15.57	8.24	4.48	3.02	1.75

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] * and ** indicate statistically significant 10% and 5%level or better, respectively.
[b] p-value = 0.1127