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Urban Fuel Demand in Ethiopia

An Almost-Ideal Demand System Approach

Zenebe Gebreegziabher, Arie J. Oskam and Demeke Bayou

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Abstract

This paper investigates the opportunities for reducing the pressure of urban centers on rural forest areas, using a dataset of 350 urban households in Tigrai in northern Ethiopia. We applied an almost-ideal demand system to fuels. Because the same fuels were not always used by households, the analysis started with a probit model of fuel use. The inverse Mills ratios derived from it were inserted into the estimation of the fuel demand system to obtain a full set of price and income elasticities. The results suggest that reducing the pressure of urban centers on local forests cannot be seen in isolation from broader development policies aimed at raising the level of education and income of the population. Higher income also stimulates the demand for fuel.

Key Words: price elasticities, income elasticities, almost-ideal fuel demand system, reducing deforestation, Ethiopia

JEL Classification: O13, O18, Q23

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Introduction

Urban centers have long been dependent on rural areas for their fuel (Barnes et al. 2004). For example, in Ethiopia, Wright and Yeshinigus (1984) reported that far back as the Axumite civilization (ca. 1000 B.C.–1000 A.D.) woodlands around Axum were cut down to supply fuel for the growing population of city dwellers. This dependence of urban centers on surrounding rural lands has aggravated forest devastation and degradation. Deforestation in contemporary times has resulted in growing fuel scarcity and higher firewood prices in urban centers (Gebreegziabher 2007). The environmental impact of urban fuel demand in general and the reliance on biofuels in particular—primary sources of forest degradation—are well established (Heltberg 2004; Edwards and Langpap 2005). This impact is much more serious where wood resources are limited, such as the African Sahel. The increasing dependence of the urban centers on rural areas has a greater environmental impact than just fuel demand (Morgan 1983; Kramer 2002; FAO 2004). Even where the level of per capita consumption of fuelwood is low, the concentration of a large number of people in smaller areas (cities and towns), coupled with the preference of urban households for charcoal over wood, intensifies the pressure on the existing local forest resources.

The fundamental economic question here is how to reduce the pressure of urban centers on rural areas for fuel—and what role policy can play in addressing the urban fuel issue. There are two answers. First, substitute or switch from one fuel to another, for example, from fuelwood

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to electricity. Electricity as a cooking fuel is cleaner and does not cause deforestation, and its use would reduce pressure on the forest resources. Second, employing technological alternatives, such fuel-efficient cooking appliances or stoves would help—but this solution is beyond the scope of this paper.

Given this pressure of urban centers, it is clear that rurally-focused solutions are insufficient to reduce environmental damage. Addressing the problem calls for a broader rural-urban approach. Previous studies (cf. Amacher et al. 1993 and 1996; Heltberg et al. 2000; Köhlin and Parks 2001) have emphasized the rural side and little research has been done on the urban dimension of the problem. This paper offers insights into urban fuel demand, by looking at four fuel sources, and draws conclusions in terms of the problem of deforestation.

Pitt (1985), Kebede et al. (2002), Chambwera (2004), Heltberg (2004), and Edwards and Langpap (2005) are among the few studies of urban fuel demand. However, their focus has been whether the poor can afford modern fuel (Kebede et al. 2002), instead of broader policy questions and the different ways to tackle the problem. Second, some of these studies (Edwards and Langpap 2005) looked at only a specific fuel in isolation, making their findings less comprehensive. Third, and more important, those studies that considered more than one fuel (Pitt 1985; Chambwera 2004) applied empirical procedures to each fuel individually and failed to take into account the interdependencies. Therefore, to provide better insight into the problem, we adopted a system of demand approach and included all the common fuels consumed by urban households.

For this paper, we investigated the possibility of reducing the pressure of urban centers on the rural areas using a cross-sectional data of 350 urban households, drawn from stratified samples of seven urban centers in Tigrai, northern Ethiopia, in the year 2003. More specifically, we analyzed the urban households' demand for various fuels. In doing so, we looked at substitution or complementarities between fuels and drew insights that may be useful in reducing the pressure on local forest resources. Finally, we looked at the implications of our findings in terms of broader policy issues.

The remaining of the paper is organized as follows. In section 1, we briefly review urban fuel demand and deforestation. Section 2 presents the model for fuel demand and the implications, using comparative static analysis. Section 3 presents the econometric model and section 4 describes the study area and the data. In sections 5 and 6, we discuss the results, and section 7 concludes.

1. Review of Urban Fuel Demand and Deforestation

Most of the previous studies (cf. Amacher et al. 1993 and 1996; Heltberg, Arndt, and Sekhar 2000; Köhlin and Parks 2001) emphasized the rural use of biofuels and little has been done with respect to the urban dimension of the problem of fuel dependence and pressure on forests. Pitt (1985), Kebede et al. (2002), Chambwera (2004), Heltberg (2004) and Edwards and Langpap (2005) are the major the exceptions.

Using data from Guatemalan households, Edwards and Langpap (2005) analyzed startup costs and the decision to switch from firewood to gas fuel. Although the magnitude of the effects was small in simulation, their results indicated that access to credit, through its effect on the ability of the household to finance the purchase of a gas stove, plays a significant role in determining the quantity of wood consumed by Guatemalan households. Their results also showed that startup costs, in terms of the purchase of a gas stove, could be a significant impediment to the adoption of liquefied petroleum gas (LPG) as an alternative to wood. Edwards and Langpap also suggested that subsidizing stoves was a more promising policy option for reducing firewood consumption and the corresponding pressure on local forests.

Pitt (1985) examined the empirical basis for both the deforestation and equity arguments of a kerosene subsidy in Indonesia with data from a large household-consumption survey. Pitt concluded that there was no evidence to support the deforestation argument for subsidizing kerosene, that the total kerosene subsidy was disproportionately captured by the nonpoor, and that the equity argument for kerosene subsidy was not strong.

With comparable household survey data from six developing countries, Heltberg (2004) analyzed the determinants of household fuel use and fuel switching, with these main findings:

- Per capita expenditure positively related to modern fuel use, whereas it related negatively to solid fuels.
- Electrification of the household enhanced modern fuel use, while it decreased use of solid fuels.
- Using a mix of fuels, both solid and non-solid, was related to larger family size.
- Higher levels of education were associated with a greater probability of the household using modern fuels and a lower probability of using solid fuels.
- The availability of tap water inside the house enhanced fuel switching.

Heltberg also noted that, particularly in urban areas, general economic development, which brought income growth, would to some extent trigger fuel switching.

Chambwera (2004) looked at data from Harare, Zimbabwe, to analyze urban fuelwood demand and other factors that explained the differences in energy consumption between electrified and non-electrified households. He found that the energy expenditure pattern of electrified households was affected by household characteristics, such as income, household size, number of rooms used by the household, and the education level of the household head (among others), while the energy expenditure pattern of non-electrified households was less affected by these characteristics.

Kebede et al. (2002) examined the domestic energy demand pattern of 10 large cities and towns in Ethiopia. They concluded that urban-specific factors (other than income), such as fuel availability and climate, appeared to be important in determining demand for modern energy.

In their synthesis of wood fuels, livelihoods, and policy interventions, Arnold et al. (2006) argued that the fuelwood discourse has shown a classic pattern of thesis and antithesis over the last few decades. They noted that the use of fuelwood in developing countries is apparently not growing at the rates assumed in the past. Nonetheless, they also acknowledged that the complex reality in developing countries could seldom be captured in clear-cut narratives and that location- or country-specific studies were needed. Regarding the impact of urbanization on consumption, they emphasized that the total consumption of wood fuels in much of urban Asia has been declining (or growing slowly), due to shifts to other fuels as incomes and city sizes increase. Africa, on the other hand, is characterized by strong growth in urban consumption of wood fuels, mainly charcoal, owing to persistently low incomes. Arnold et al. also argued that in most studies the effect of income on fuelwood consumption turns out to be small, irrespective of how income is measured. His calculations were in the range of -0.31 to 0.0,6, and relatively few of these observed income elasticities were significantly different from zero.

Gundimeda and Köhlin (2008) found that variety in life styles and opportunity costs of time, as explained by diverse employment categories, mean different fuel choices. They also argued that earlier energy policies in India had a major impact on domestic fuel choices, given the responsiveness of cross-price elasticities coupled with substantial subsidies.

2. Consumer Demand Theory: Comparative Static Analysis

Consider a consumer who derives utility from consumption of a vector of n commodities denoted by q. Furthermore, assume that vector q includes broader categories of consumption goods, such as food, fuel, and non-fuel non-food. Let *u* denote the utility the consumer derives from consuming these goods. Following the standard formulation of utility function (see Deaton and Muellbauer 1980; Sadoulet and de Janvry 1995), the household's utility function can be written as:

$$u(q;h) , \qquad (1)$$

where *h* stands for the vector of individual characteristics of the household. The budget constraint is:

$$p'q = y , \qquad (2)$$

where *p′* is an *n*-dimensional row vector of prices; and *y* is the amount of income that can be spent on the different commodities. The objective of the household is to maximize utility by choosing *q*, subject to the budget constraint given in equation (2). Therefore, the Lagrangean of the consumer's maximization problem can be rewritten as:

$$\mathrm{L} = u(q,h) + \lambda(y - p'q) , \qquad (3)$$

where λ is a Lagrange multiplier. Solving for the Lagrangean function in equation (3), we get a set of i = 1,…, *n* observed demand equations:

$$q_i = q_i(p,y;h) . \qquad (4)$$

Upon partially differentiating equation (4) with respect to income y, and prices p_j, we get *n* income and n^2 price slopes. Then, multiplying the income slopes and price slopes by their respective income/quantity and price/quantity ratios, we get *n* income elasticities and n^2 price elasticities that are useful for comparative statics:

$$\frac{\partial q_i}{\partial y}\frac{y}{q_i} = \eta_i \text{ , and} \qquad (5)$$

$$\frac{\partial q_i}{\partial p_j}\frac{p_j}{q_i} = \varepsilon_{ij} . \qquad (6)$$

In comparative-static analysis, the objective is to determine how an economic variable of interest—for example, quantity demand in our case—responds to changes in the value of some parameter or exogenous variables. Simply put, we want to know how the optimal choice changes as a parameter changes.

Deaton (1990) assumed that "geographically clustered households," (i.e., households residing in the same area) face the "same prices." For Tigrai, we do not make this assumption and allow households to face different prices. This makes sense because the markets for fuels in the study area are fragmented and far apart. In addition, the possibility that fuelwood trade takes place on a one-to-one basis is very high. While the sign of the cross-price variables might not be predicted beforehand, own-price variables are expected to have negative signs.

Note that, if preferences are separable, the n vector of commodities q in equation (1) can be partitioned into groups, say three, and that the utility function can be represented as:

$$u = v(q_A, q_F, q_O) = f[v_A(q_A,), v_F(q_F), v_O(q_O)] \, , \tag{7}$$

where $f(\ )$ is an increasing function and v_A, v_F, and v_O are the subutility functions associated with food, fuel goods, and other goods or services, respectively. The idea is that, due to the complexity for consumers in making choices among a large array of alternatives, income is allocated to broad groups of goods, such as food, fuel, and other goods, in the first stage. In the second stage, the budget for fuel is then allocated to specific items, such as electricity, kerosene, and wood. The implication of this step-by-step budgeting process is that decisions made at each stage can be regarded as corresponding to a utility maximization problem of their own. (Deaton and Muellbauer 1980, 127–28; Sadoulet and de Janvry 1995, 36–37)

3. Econometric Model

The econometric model or empirical framework outlined here is used with demand equations and budget shares of specific fuel goods (such as electricity, kerosene, charcoal, and wood), in relation to a household's total expenditure. In general, fuel expenditure accounts for about 20 percent of a household's total budget.

For the empirical demand analysis, we used the almost-ideal demand system. This demand system derives from a utility function specified as a second-order approximation to any utility function (Sadoulet and de Janvry 1995, 43–44). The demand functions are specified in the budget share as follows:

$$w_{Fi} = a_F + \sum_J b_{FJ} \ln p_J + c_{Fi} \ln \frac{y_i}{P} \ , \tag{8}$$

where w_{Fi} in equation (8), defined as $w_{Fi} \equiv \frac{y_{Fi}}{y_i}$, is fuel F's budget share in household i's budget; y_{Fi} is household i's expenditure on the fuel F ($F = W, C, K, E$) [i.e., wood, charcoal, kerosene, and electricity, respectively] consumed by the household; p_J is price of Jth good; y_i is household i's total expenditure on all goods; and P is the consumer price index. This share is assumed to be a linear approximation of the logarithm of the price of *J*th good and the logarithm of the ratio of total expenditure to price index.

However, some of the households were observed to have not consumed some of the fuel goods, at least during the period considered, implying zero values for corresponding observations of budget shares in equation (8). The dependent variable is thus censored, rendering ordinary least squares estimates to be biased. With censoring or zero observations, it fails to comply with the standard assumptions with respect to the disturbance term. This problem is solved by using a two-step estimation procedure that combines a probit analysis with standard seemingly unrelated regression (SUR). Therefore, we can rewrite the system of fuel demand equations to be estimated as (Sadoulet and de Janvry 1995):

$$w_{Fi} = a_F + \sum_J b_{FJ} \ln p_J + c_{Fi} \ln \frac{y_i}{P} + \mu_F \xi_{Fi} + \upsilon_{Fi} \ , \qquad (9)$$

where the additional terms ξ_{Fi} and υ_{Fi} on the right hand side of equation (9), respectively, stand for the inverse Mill's ratio and the residual term of fuel *F* for household *I*; and μ_F is the coefficient corresponding to the inverse Mill's ratio. Coefficients or parameters are subject to standard restrictions in neoclassical theory.[1]

Once we estimated the coefficients with the restrictions imposed, then the price and income elasticities could be calculated from the coefficient estimates (see Sadoulet and de Janvry 1995):

$$\varepsilon_{FF} = -1 + \frac{b_{FF}}{w_F} - c_F \ , \ \varepsilon_{FJ} = \frac{b_{FJ}}{w_F} - \frac{c_F}{w_F} w_J \ , \ \eta_F = 1 + \frac{c_F}{w_F} \ ;$$

where ε_{FF} and ε_{FJ}, respectively, stand for own-price and cross-price elasticity; and η_F is income elasticity of demand for fuel *F*. The income elasticity enables us to characterize whether a specific fuel good is normal, inferior, or a luxury good, depending on the value and sign of the coefficient.

Note that the inverse Mill's ratio ξ_{Fi} comes from the first-step estimation of household *i*'s decision to consume a specific fuel good *F*. For exposition, consider a decision involving a

[1] Coefficients/parameters are subject to restrictions, $\sum_F a_F = 1$, $\sum_F b_{FJ} = 0$, $\sum_F c_F = 0$, $\sum_J b_{FJ} = 0$, and $b_{FJ} = b_{JF}$. Note that the first three are adding up restrictions, whereas the last two are referred to as homogeneity and symmetry, respectively. Estimation was carried with these restrictions imposed.

choice between consuming and not consuming. That is, the decision whether or not to consume a specific fuel good *F*, such as wood, by household *i* essentially involves a choice between yes or no. Such dichotomous choices are best modeled as probit. Hence, we can specify the probit model as:

$$\text{Prob}\ (q^*_{Fi} = 1) = \text{Prob}\ (f_{Fi}(p_F, y_i, h_i) + e_{Fi} > 0)\ , \qquad (10)$$

where q^*_{Fi} is equal to 1 if household *i′* consumes fuel good *F*, and zero otherwise; p_F, y_i, and h_i, respectively, are the prices of related fuel goods, income, and characteristics that apply to the household; and e_{Fi} is a residual term. Then, the inverse Mill's ratio is generated from the probit estimation as:

$$\xi_{Fi} = \varphi(f_{Fi})/\psi(f_{Fi})\ , \qquad (11)$$

where φ is the probability density function and ψ the cumulative density function of the standard normal distribution of the residual term e_{Fi}.

The demand functions for the different fuel types considered were estimated using SUR. Estimation of an almost-ideal fuel demand system, as in equation (9), presupposes the use of a price index often calculated from the dataset. In our case, the general consumer price index for the study region (CSA 2006) corresponding to the year in consideration was used as the price index.

4. Study Area, Data Description, and Sampling

Tigrai is the most northern region of Ethiopia. Traditional biofuels are the sole or dominant sources of fuel for the great majority of the urban population. Table A1 in the appendix presents the energy consumption pattern of urban households in Ethiopia, both for the country overall and Tigrai in particular. In Tigrai, in 1995, biofuels accounted for over 90 percent of fuel consumed by urban households. However, in 2003, the share of traditional fuels declined by about 6 percent (see the columns for urban Tigrai in table A1 in the appendix). Electricity consumption in urban Tigrai increased from 0.8 percent in 1995 to 5.8 percent in 2003.

Of the various end uses, baking *injera*[2] and normal cooking are the two most important uses in urban domestic fuel consumption in Ethiopia. Included in normal cooking is preparing or

[2] *Injera* is a ubiquitous pancake-like sourdough bread to Ethiopia. It is prepared in the household and uses the largest part of total domestic fuel consumption.

cooking sauce, soup, or stew (*wet*) from meat, vegetables, or other comestibles to eat with injera. Boiling water, making coffee, and the like, which involve lighting a fire several times a day, are also considered normal cooking. In all settlement typologies, injera baking is the major consumer of fuelwood and accounts for over 50 percent of the total household fuel consumption (Gebreegziabher 2004).

Electricity and petroleum products are the two modern fuel sources available in Ethiopia. The public utility EEPCO (Ethiopian Electric Power Corporation) is the major supplier of electricity, supplemented by a few community and privately owned systems. The country has two power supply systems in the country: the interconnected system (ICS), which has grid connections and is mainly supplied from hydropower plants; and the self-contained system (SCS), which is made up of separate power-generating units operating with diesel. Table A2 in the appendix shows the role of these two systems in the overall electricity/power supply of Ethiopia. The electricity supply has improved considerably during the past few years. For example, the overall electricity supply increased by 37 percent in the last five years (table A2 in the appendix), with the main growth coming from the expansion of hydropower supply. But, Ethiopia has a long way to go.

EEPCO has about 800,000 customers throughout the country, ranging from domestic users to large industries requiring high voltage. Electricity constitutes less than 4 percent of the total domestic consumption of urban households, and the current level of electrification is only about 14 percent (ACD 2003). By and large, lighting is the dominant end use in the domestic sector and the use of electricity for baking is limited to larger towns and to a very limited number of households, which also implies an increased pressure on local forests.[3]

Among petroleum products, kerosene and LPG are the most important, mainly available in urban areas, although there is some consumption in rural areas. In cities and large towns, kerosene is used for normal cooking by some households. However, in medium and small towns with no electricity supply, kerosene is most often used for lighting and in rare cases for cooking.

[3] The growing demand for forest products can be viewed as source of economic growth by creating demand for these products and thereby enhancing forest growth (Foster and Rosenzweig 2003), particularly in situations where the supply of forest products, such as firewood, is organized by firms (farm households) engaged in production of firewood from allocations of own resources. The reason demand is seen as a pressure is because the supply of biofuels in not organized in such a way that farmers (firms) produce fuelwood from their own resources allocation. Rather, it is collected from communal and natural forests, creating a pressure on existing already-scarce forest resources.

Data was collected in one period from a stratified sample of 350 urban households in Tigrai. Urban centers in the study area were categorized as four settlement types: city plus large, medium, and small towns, based on their population (>$100x10^3$, $25\text{-}100x10^3$, $5\text{-}25x10^3$, and <$5x10^3$, respectively), according to ENEC & CESEN (1986) and EESRC (1995). The 1994 Population and Housing Census (CSA 1995) identified a total number of 74 towns in Tigrai. Focal towns were identified, subject to time and budget constraints.

To get an idea of the current population, and basing the sample on this figure, the population of the focal towns was projected to 2000 and 2003. Then, proportionate sampling by importance of town size by population share was applied to this estimate of the current population.

Table 1. Summary Statistics of Variables Considered in the Analysis (n = 350), 2003

Variable	Mean	Std. dev.	Min.	Max.
Family size	4.925	2.196	1	10
Age of household head	49	14	18	95
Education of household head/highest grade completed				
Illiterate (percent)	*39%*			
Grade 1-3	15			
Grade 4-6	18			
Grade 7-8	11			
Grade 9-11	5			
Grade 12 and above	12			
Employment type/occupation of household head				
Self employed (in percent)	*69%*			
Public employee	16			
Private employee	15			
Use of particular fuel (in percent)				
Wood	*93%*			
Dung	*26%*			
Charcoal	*75%*			
Kerosene	*74%*			
Electricity	*80%*			
Wood price (in ETB/kg)[a]	0.47	0.259	0.05	3.00
Dung price (in ETB/kg)	0.32	0.121	0.02	0.57
Charcoal price (in ETB/kg)	0.64	0.299	0.08	1.67

Kerosene price (in ETB/liter)	2.36	0.389	1.00	5.00
Electricity price (in ETB/kWh)	0.28	0.206	0.01	3.66
Total expenditure (in ETB)	6,910	5,087	1,045	46,398
Budget share of fuel	0.206	0.080	0.018	0.469
Budget share of food	0.620	0.112	0.085	0.875
Budget share of other goods and services	0.174	0.117	0	0.878
Budget share of wood	0.105	0.075	0	0.403
Budget share of dung	0.011	0.027	0	0.250
Budget share of charcoal	0.035	0.033	0	0.193
Budget share of kerosene	0.021	0.020	0	0.128
Budget share of electricity	0.030	0.030	0	0.196

[a] Unit values were used as proxies for prices.

Note: ETB = Ethiopian birr; ETB 1 = US$ 0.116 during the survey period.

A questionnaire was developed and used to collect data on food and non-food–non-fuel expenditures, expenditure on the different fuels consumed (firewood, charcoal, kerosene, electricity, etc), income, and types of cooking appliances (stoves) used. In addition, fuel preferences and reason(s) for not using a specific cooking appliance or stove type was also gathered. Five people were trained to administer the questionnaire and collect the data. Summary statistics of the variables considered in our analysis are provided in table 1. Although the study (from the data collected) considered all possible fuel types and categories, none of the sample households used LPG or crop residues (biomass). In addition, smaller proportions of the households, about 26 percent, used dung, which was mainly collected for free. Thus, our empirical analysis focused only on four fuel goods: firewood, charcoal, kerosene, and electricity.

5. Discussion of Results for Household Fuel Choice

A fuel-specific probit model was estimated to identify the determinants of fuel choice, namely, factors explaining a household's decision to consume a particular fuel or combination of fuels. It provided insights on how the different sources of fuel are related to each other. The results are presented in table 2. (The results are a summary of individual probit regression results by fuel good.)

Injera baking and general cooking are the two most common end uses of urban domestic energy consumption in Ethiopia. Fuelwood, electricity, and dung are mainly used to bake injera, while charcoal and kerosene are used for other cooking. The cooking appliances or types of stoves used by households are also quite different. Hence, interdependencies might be expected among choices of fuelwood, electricity, and dung, as well as between choices of charcoal and kerosene. Therefore, we ran test regressions of three different models.

First, we ran a trivariate probit regression on choices of fuelwood, electricity, and dung. However, the estimation collapsed because none of the iterations turned concave and they failed to converge. Next, as an alternative, we ran two bivariate probit regressions, one for the choices between fuelwood and electricity and the other between charcoal and kerosene.[4] However, in both cases, we could not reject the null hypothesis that the error correlation was $\rho=0$, suggesting that the choices were independent. This also gave us the confidence that we could run individual probit regressions of the household's decision to consume particular fuel, so the regression results of the third model are presented and discussed here.

The probit model was used as an intermediate input to calculate the inverse Mills ratio (see table 2). Normally, probit command (estimation) drops variables that perfectly predict (completely determine) the outcome in the dependent variable. Therefore, only results for coefficient estimates of the remaining variables are presented. Overall validity of model regressions in all cases turned out quite significant. Considering the likelihood ratio test, for example, the computed value chi-square was greater than the critical value at far better than a 1 percent level of significance, particularly in the case of charcoal, kerosene, and electricity. This implied that the restrictions do not apply, or put differently, this was in favor of the alternative hypothesis that all the explanatory variables included helped explain the variation.

The overall fit of model regressions also performed well in all cases, despite some variations from one to the other.[5] For example, the model explained about 37 percent of the variations in the decision to consume electricity, but only 12 percent for charcoal. Also the predicted probabilities were quite substantial.

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[4] For details about bivariate and tri(multi)variate probit models, see Cameroon and Trivedi (2005, 519–23) and Greene (2003, 710–19).

[5] McFadden's pseudo R^2, defined as McFadden's $R^2 = 1-\frac{\log \hat{L}_1}{\log \hat{L}_0}$, was used to assess the overall fit of the model, where $\log \hat{L}_1$ is the maximized likelihood when both the constant term and the explanatory variables are in the model, and $\log \hat{L}_0$ is the maximized likelihood when only the constant term is in the model.

As is clear from table 2, the prices of related goods, household income (expenditure), and other household characteristics were the explanatory variables. Among the other household characteristics considered was employment type or occupation, to see whether or not it made a difference being self-employed or a public/private employee.

Table 2. Probit Estimates of the Decision to Consume Fuel *F*

Explanatory variable	**Dependent variable consume fuel *F* (q_{Fi} * = 1 if yes, 0 otherwise)[a]**			
	Wood	***Charcoal***	***Kerosene***	***Electricity***
Price of wood				0.719** (0.365)
Price of charcoal	-0.421 (0.490)		1.563*** (0.382)	3.194*** (0.558)
Price of kerosene	0.134 (0.275)	0.551** (0.235)		
Price of electricity		0.185 (1.635)	1.803 (2.991)	
Household income/expenditure (‘000 ETB)	-0.014 (0.026)	0.122*** (0.044)	0.139*** (0.035)	0.020 (0.029)
Family size	-0.018 (0.074)	-0.137** (0.060)	-0.045 (0.052)	0.028 (0.061)
Age of household head	0.004 (0.014)	0.023** (0.011)	-0.018** (0.008)	0.023** (0.010)
Education of household head[b]	-0.165*** (0.065)	-0.024 (0.056)	-0.064 (0.046)	0.172** (0.071)
Employment type/occupation (1 if self employed, 0 otherwise)	0.065 (0.078)	0.007 (0.058)	0.032 (0.046)	-0.084 (0.056)
Constant	1.816* (1.058)	-1.343 (0.904)	-0.666 (0.991)	-2.626*** (0.623)
n	350	350	350	350
Share of zeros (in percent)	*7.45*	*24.86*	*25.71*	*20.31*
Predicted probability at (mean)	0.951	0.862	0.770	0.921
Pseudo-R^2	0.130	0.123	0.141	0.369
LR $\chi^2(7)$	13.18	22.37	35.75	83.87
Prob>χ^2	0.068	0.002	0.000	0.000

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

[b] Education of head (highest grade completed) was captured on a 0-11 scale; 0 = Illiterate, 1 = grade 1–3, 2 = grade 4–6, 3 = grade 7–8, 4 = grade 9–11, 5 = grade 12, 6 = certificate, 7 = diploma not completed, 8 = degree not completed, 9 = diploma, 10 = degree, and 11 = post-graduate, respectively.

Note: Standard error is in parentheses.

Although the rest of the variables turned out to be insignificant, education of head significantly and negatively influenced the decision to consume wood (column 1, table 2) and the price of kerosene positively and significantly influenced the decision to consume charcoal (column 2, table 2). Moreover, household income, family size, and age of household head significantly influenced the decision to consume charcoal. The fact that education of the household head significantly and negatively influenced the decision to consume wood implies that it is less likely a household will consume wood the higher the level of education. The fact that the price of kerosene positively influenced the decision to consume charcoal also suggests that charcoal and kerosene are substitutes. Similarly, the price of charcoal positively and significantly influenced the decision to consume kerosene (column 3, table 2). In addition, household income and age of household head were statistically significant. The price of wood, price of charcoal, age of household head, and education of household head turned out to be significant and positive for the decision to consume electricity (column 4, table 2). The fact that the price of wood positively influenced a household's decision to consume electricity indicates that wood and electricity are substitutes.

6. Discussion of Results for Fuel Demand System

We estimated a system of demand equations to explain the demand for the different fuel goods considered. An almost-ideal fuel demand system was specified and SUR used in the estimation. (The results are in table 3.) The main explanatory variables were own-price, price of related good, and household income/expenditure. In addition, the inverse Mills ratio was included as explanatory variable to correct for the problem of censoring or zero observations.

In the wood demand equation (column 1, table 3), own-price, price of electricity, and household income were highly significant and negative, whereas charcoal price and price of kerosene had no significant effect on demand for wood. The inverse Mill's ratio was also highly significant. For charcoal (column 2, table 3), only the income variable turned out to be statistically significant, and the price variables were insignificant. The inverse Mill's ratio was also significant in this case. Own-price and income were highly significant in the kerosene demand function and all cross-price variables turned out to be insignificant (column 3, table 3). The price of wood and household income had statistically significant effects on electricity demand with negative and positive signs, respectively, while the rest of the price variables were insignificant (column 4, table 3). However, care needs to be taken in the interpretation of these results.

Table 3. Seemingly Unrelated Regression Results of Almost-Ideal Fuel Demand System

Explanatory variable	Dependent variable share in total expenditure of fuel *F* (w_F)[a]			
	Wood	***Charcoal***	***Kerosene***	***Electricity***
Ln (price of wood)	0.020*** (0.008)	-0.005 (0.005)	-0.004 (0.003)	-0.011** (0.006)
Ln (price of charcoal)	-0.005 (0.005)	0.004 (0.005)	-0.001 (0.003)	0.008 (0.007)
Ln (price of kerosene)	-0.004 (0.003)	-0.001 (0.003)	0.007*** (0.003)	-0.007 (0.005)
Ln (price of electricity)	-0.011** (0.006)	0.008 (0.007)	-0.007 (0.005)	0.011 (0.008)
Ln (total expenditure/P)	-0.022*** (0.007)	-0.016*** (0.005)	-0.008*** (0.003)	0.007* (0.004)
Inverse Mill's ratio (ξ)	-0.086*** (0.032)	-0.107** (0.055)	-0.020 (0.022)	-0.002 (0.049)
Constant	0. 191*** (0.031)	0.151*** (0.036)	0.062*** (0.019)	0.024 (0.031)
R^2	0.215	0.076	0.067	0.078
χ^2	46.95	17.60	12.78	11.47
P-value	0.000	0.007	0.047	0.075

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

Note: Standard error is in parentheses.

For a more straight forward interpretation of results, we calculated price and income elasticities of demand (in table 4). All own-price elasticities showed the expected negative sign. Specifically, the demands for firewood, charcoal, and kerosene were price inelastic with own-price elasticity of less than 1. Arnold et al. (2006) found that, with the exception of evidence in India, most estimates of own-price elasticity reflect that the demand for fuelwood and charcoal, particularly in urban areas are price inelastic. The fact that the demand for firewood and charcoal, in our case, turned out price inelastic was consistent with their findings. Nonetheless, the magnitude we found was substantially larger, -0.83 in the case of firewood, than suggested by them, which implies that urban households in Ethiopia are relatively more price responsive than perhaps other African countries or South Asia.

The cross-price elasticities related to firewood and electricity were statistically significant at the 5 percent level or less. However, most cross-price elasticities were not significantly different from zero. Elasticity of electricity demand, with respect to the price of wood, turned out to be significant and negative. Apparently, wood and electricity can be substitutes, particularly with respect to injera baking. It may be that the rise in wood price does not directly affect the amount of electricity demand. Typically, in the context of our study area, one stove technology can be used only for one particular fuel good. Two fuel goods involve the use of entirely different cooking appliances (stoves). Therefore, it is possible that a rise in the price of wood induces household's decision to consume electricity and hence invest in or adopt an electric *mitad* (a specific type of electric cooking stove) and its sign turns negative. Alternatively, in areas where electricity is available and intensively used, there could be good working markets and the price of wood is relatively low, which turns its sign negative.

Table 4. Price and Income Elasticities of Demand for Fuel *F*

Parameter	**Elasticity (ε_{FF}, ε_{FJ}, η_F)**			
	Wood	***Charcoal***	***Kerosene***	***Electricity***
Price of wood	-0.831	-0.095	-0.150	-0.391
Price of charcoal	-0.041	-0.870	-0.035	0.159
Price of kerosene	-0.034	-0.019	-0.659	-0.238
Price of electricity	-0.099	0.243	-0.322	-0.642
Income/expenditure	0.791	0.543	0.619	1.233

Arnold et al. (2006) argued that in most studies the effect of income on fuelwood consumption turns out to be small, irrespective of how income is measured. Their results were in the range of -0.31 to 0.06 and relatively few of these observed income elasticities were significantly different from zero. In our case, however, income/expenditure elasticities for all fuel goods were positive and significantly different from zero, implying that none of the fuels we considered were inferior goods. In fact, there is no support for the "energy ladder" hypothesis,[6] contrary to what Arnold et al. suggested, possibly because Ethiopia is at the bottom of the energy ladder.

The magnitude of the income elasticities, however, varied for the different fuels. For example, while the demand for electricity was income elastic (>1), the demand for wood, charcoal, and kerosene was income inelastic. Moreover, the magnitude of the income elasticities

[6] The "energy ladder" hypothesis postulates a progression to modern fuels as a household's economic well-being, i.e., income, rises, and implies that fuelwood is an "inferior good" (Arnold et al. 2006).

of demand for both firewood and charcoal was substantially larger than suggested by Arnold et al. (2006). Technically speaking, while electricity can be characterized as a luxury fuel good, the latter three appear to be necessities.

Our results also revealed that charcoal and kerosene, and wood and electricity, are substitutes (interchangeable), and that charcoal and fuelwood might not be (perfectly) interchangeable. Moreover, our findings illustrate the diversity of lifestyles[7] and end-uses (purposes) for which these fuels are used in different local circumstances. For example, in countries like Ethiopia, fuelwood is mainly used for injera baking and charcoal for other routine cooking in urban areas. The cooking appliances or stoves are also quite different, which inhibits the ease of substitution, and supports the argument that charcoal and fuelwood might not be (perfectly) interchangeable.

7. Conclusions

We investigated the possibilities for reducing the pressure of urban centers on the rural areas for fuel. First, we specified and estimated a probit regression of the household's decision to consume specific fuel good and then we estimated an almost-ideal demand system for fuel goods using seemingly unrelated regression. We drew the following conclusions.

In addition to prices of related goods household income (expenditure), other household characteristics, such as family size, and age and education of household head, are important variables for explaining a household's decision to consume a particular fuel. Nonetheless, the relative importance of each of these factors varied from one fuel good to another. It does not make a difference whether the household head is self employed or a public or private employee. While it increases the likelihood that the household will consume electricity, improvement in income and education decreases the probability that the household will consume wood. This is quite interesting because it means reduced pressure on wood resources. Moreover, the probit regression results of a household's decision to consume fuel suggest that charcoal and kerosene are substitutes and that wood and electricity are substitutes.

Estimation results of the fuel demand system were used to calculated price and income elasticities of demand and to characterize respective fuel goods. The demands for firewood,

[7] The term lifestyle is used to mean how people (individuals or in group) live, and specifically in this paper how they cook, including their food habits.

charcoal and kerosene were found to be price inelastic, with own-price elasticity of less than 1. The cross-price elasticities related to firewood and electricity were also important in terms of explaining quantity demanded of the respective fuel good. Elasticity of electricity demand for the price of wood had an unexpected negative sign. One reason for this unexpected negative sign could be because the substitution is not immediate. Alternatively, it could be that in areas where electricity is available and intensively used, there are good working markets and the price of wood is relatively low. Income elasticities for all the fuel goods were positive, suggesting that none of fuels considered are inferior goods. The magnitude of the income elasticities, however, varied for the different fuels. For example, the demand for electricity was income elastic (>1), but the demand for wood, charcoal, and kerosene was income inelastic. Technically speaking, while electricity can be characterized as a luxury fuel good, the latter three appear to be necessities.

The results of this study also have considerable implications for how urban pressure on rural areas could be reduced. The significant positive impact we saw was the potential to reduce the pressure on rural areas by raising education and income levels. In this respect, at least two points are discernible.

One, income and education are negatively related to a household's decision to consume fuelwood. These results suggest a that a policy that raises the level of education by one unit, for example, from lower primary (grades 1–3) to higher primary (grades 4–6), would reduce the probability an average household consumes wood by 0.02 (all things being equal). Two, household income and education of the household head were positively associated with a household's decision to consume electricity, that is, the likelihood increased. In addition, our findings also revealed a considerable potential for reducing the pressure on local forest resources by substituting or switching from fuelwood to electricity. This switch would save the entire amount (100 percent) of fuelwood that would have been consumed by the household.

Appendix

Table A.1 Final Energy Consumption of Urban Households in Ethiopia and Tigrai

Fuel type	Ethiopia overall (1998–1999)		Urban Tigrai (1995)	Urban Tigrai (2003)[a]	
	Quantity (in terajoules)	*Share (%)*	*Share (%)*	*Quantity (in megajoules)*	*Share (%)*
Wood and tree residues	34,969.38	66.1	49.0	29,187.80	53.2
Crop residues	2,823.65	5.3	2.2	0.00	0.0
Dung	3,262.90	6.2	2.6	3,526.11	6.4
Briquettes and biogas	0.00	0.0	0.0	0.00	0.0
Charcoal	5,855.81	11.1	40.9	15,666.16	28.5
Electricity	1,832.05	3.5	0.8	3,176.03	5.8
Petroleum fuels	4,161.24	7.8	4.4	3,325.77	6.1
Total	52,905.03	100.0	99.9	54,881.87	100.0

[a] Own survey results for representative household and RWEDP (1997) were used for conversion into energy units.

Source: ADC (2003) and EESRC (1995)

Table A.2 Energy/Electricity Production in Ethiopia by System/Source and Year (in GWh)

System/source	Year				
	1999–2000	***2000–2001***	***2001–2002***	***2002–2003***	***2003–2004***
ICS					
Hydro	1631.5	1774.3	1975.2	2007.1	2262.5
Diesel	4.0	2.1	0.1	21.1	16.1
Geothermal	20.0	5.1	1.0	0.0	0.0
Total	1655.5	1781.5	1976.3	2028.2	2278.6
SCS					
Hydro	14.3	15.5	16.6	16.5	16.5
Diesel	19.0	14.8	16.5	19.0	22.7
Total	33.3	30.3	33.1	35.5	39.2
ICS+SCS					

Hydro	1645.8	1789.8	1991.8	2023.6	2279.0
Diesel	23.0	16.9	16.6	40.1	38.8
Geothermal	20.0	5.1	1.0	0.0	0.0
Total	1688.8	1811.8	2009.4	2063.7	2317.8

Note: GWh = gigawatt hours.

Source: Z. Gebreegziabher, 2007, “Household Fuel Consumption and Resource Use in Rural-Urban Ethiopia,” PhD diss., Department of Social Sciences, Wageningen University, The Netherlands.

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