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Urban Energy Transition and Technology Adoption

The Case of Tigrai, Northern Ethiopia

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Urban Energy Transition and Technology Adoption: The Case of Tigrai, Northern Ethiopia

Zenebe Gebreegziabher, Alemu Mekonnen, Menale Kassie, and Gunnar Köhlin

Abstract

Dependency of urban Ethiopian households on rural areas for about 85 percent of their fuel needs is a significant cause of deforestation and forest degradation, resulting in growing fuel scarcity and higher firewood prices. One response to reducing the pressure on rural lands is for urban households to switch fuel sources (from fuelwood to electricity, for example) to slow deforestation and forest degradation and reduce indoor air pollution. However, such an energy transition is conditioned on the adoption of appropriate cooking appliances or stove technologies by the majority of users. This paper investigates urban energy transition and technology adoption conditions using a dataset of 350 urban households in Tigrai, in northern Ethiopia. Results suggest that the transition to electricity is affected by households adopting the electric *mitad* cooking appliance, which in turn is influenced by the level of education and income, among other things.

Key Words: urban energy transition, electric *mitad* cooking appliance, technology adoption, bivariate probit, Tigrai, Ethiopia

JEL Classification: Q4, Q41, Q48

Contents

Urban Energy Transition and Technology Adoption: The Case of Tigrai, Northern Ethiopia

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Introduction

Urban households have long been dependent on rural areas for their fuel (Barnes et al. 2004). In Ethiopia, Wright and Yeshinigus (1984) reported that as 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 long history of urban dependence on surrounding rural lands and the associated increase in population has aggravated the level of deforestation and forest degradation, particularly in contemporary times. Deforestation in modern Ethiopia 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, in terms of contributing to forest degradation, is well documented (Heltberg 2004; Edwards and Langpap 2005). This impact is much more serious in environments with limited wood resources, such as the African Sahel (Morgan 1983; Kramer 2002; Kramer 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 question is how to reduce the pressure of urban centers on rural areas for energy sources. One answer is to switch from one source of fuel to another (energy transition), such as substituting fuelwood for electricity. Electricity is a cleaner source of energy for cooking and does not cause deforestation. However, such a transition is conditioned by

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whether a majority of households adopt a more efficient cooking appliance or stove technology. In addition, recent evidence shows that the combined contribution of emissions from deforestation and forest degradation accounts for about 18 percent of global greenhouse gas emissions (Stern 2007; IPCC 2007). Reducing deforestation and forest degradation through comparatively simple technological means (using electricity or solar power, for example) can significantly contribute to climate change mitigation. Thus, understanding the factors that determine the adoption rate of different fuel sources and cooking appliances is important for policy and the welfare of citizens.

A review of the relevant literature reveals a number of issues. First, many previous studies emphasized the rural side and little research looked at the urban dimension of the fuel problem. Second, those few studies that did consider the urban side focused on whether the poor could afford modern fuel (Kebede et al. 2002), rather than broader policy questions and different solutions to the problem. Third, the transition from traditional to modern fuels has often been conceptualized in the literature as a relatively straightforward three-stage process (Barnes et al. 2004).

Wood fuel is the predominant energy source in stage 1. Stage 2 is marked by local deforestation, manifested by a decrease in wood availability and the emergence of markets for charcoal and kerosene. Stage 3 is characterized by developed markets, rising incomes, and large-scale fuel switching to liquefied petroleum gas (LPG) and electricity. However, such an energy transition may not be so simple and the extent of the environmental and health effects (positive externalities) is conditioned by technology adoption. Moreover, knowledge about the characteristics, particularly empirical evidence, of the behavioral factors underlying cooking appliance or stove technology adoption is thin, if not non-existent.

This paper attempts to investigate urban energy transition and technology adoption as a possible means of reducing the pressure of urban centers on rural areas. The study uses a dataset of 350 urban households from stratified samples of seven urban centers in Tigrai, in northern Ethiopia, from the year 2003. More specifically, the paper aims 1) to assess the electric *mitad*[1]) cooking appliance adoption rate and how it affects urban energy transition, and (2) analyze factors explaining urban households' fuel choice among various fuels.

[1] *Mitad* is the local name for a stove that is exclusively used for baking *injera*, the staple bread in Ethiopia.

The remainder of the paper is organized as follows. In section 1, the paper briefly reviews the literature on fuel use, urban energy transition, and deforestation. Section 2 presents the model for fuel demand and its implications, using comparative statistics. Section 3 provides the empirical model. Section 4 describes the study area and section 5 covers the sampling and data description. Section 6 presents results and discussions, and section 7 concludes.

1. A Review of Fuel Use, Urban Energy Transition, and Deforestation

Many of the previous studies (cf. Amacher et al. 1993 and 1996; Heltberg, Arndt, and Sekhar 2000; Köhlin and Parks 2001) have emphasized the rural side—with little research on the urban dimension—of the fuel problem. Using data from Guatemalan households, Edwards and Langpap (2005) analyzed start-up costs and the decision to switch from firewood to gas. Although the magnitude of the effects was small upon simulation, their results indicated that access to credit, due to its effect on the ability of the household to finance the purchase of a gas stove, played a significant role in determining the quantity of wood consumed by Guatemalan households. Their results also showed that start-up costs (the purchase of a gas stove) could be a significant impediment to the adoption of LPG as an alternative to wood. Edwards and Langpap (2005) also suggested that subsidizing stove purchases was a more promising policy option for reducing firewood consumption, as well as relieving pressure on local forests.

Using a large household consumption survey data, Pitt (1985) examined the empirical basis for both the deforestation and equity arguments for subsidizing kerosene in Indonesia. Pitt concluded, however, that there was no evidence to support the deforestation argument for the kerosene subsidy. Pitt also concluded that the total kerosene subsidy was disproportionately captured by the non-poor and that the equity argument for kerosene subsidy could not be strong.

Kebede et al. (2002), Chambwera (2004), and Heltberg (2004) are among the few other studies on urban fuel choices. Using 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 uses, while it decreased usage of solid fuels
- Use of more fuels (a mix of both solid and non-solid fuels) 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
- Availability of tap water inside the house enhanced fuel switching

Heltberg also noted that, particularly in urban areas, the general economic development bringing income growth to some extent helped trigger fuel switching.

Using data from Harare, in Zimbabwe, Chambwera (2004) analyzed urban fuelwood demand and factors to explain differences in the energy consumption pattern 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, the number of rooms used by the household, and the education level of the head, among other influences. (The energy expenditure pattern of non-electrified households was less affected by these characteristics.)

Kebede et al. (2002) also examined domestic energy demand pattern in 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 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. For example, what occurs in Bangladesh might not be the case in Ethiopia, hence the need for location- or country-specific studies. Regarding the impact of urbanization on consumption, they emphasized that total consumption of wood fuels in much of urban Asia has been declining or growing only slowly, with shifts to other fuels as income and city size increases.

On the other hand, Africa is characterized by strong growth in urban consumption of wood fuels, primarily charcoal instead of fuelwood, owing to persistently low incomes. Gundimeda and Köhlin (2008) found that diversity of life styles and opportunity costs of time, as explained by various employment categories, mean different fuel choices. They also argued that past energy policies in India had major impacts in terms of shaping domestic fuel choices, given the responsiveness of cross-price elasticities coupled with substantial subsidies.

Barnes et al. (2004) noted that urbanization is also a process of fundamental transformation in human behavior and not merely an increase in population density. They argued that the pattern of the relationship among urbanization, fuel choice, and household energy consumption involves dynamic processes and a complex set of feedbacks. They also argued that such complexities give rise to diverse possibilities of transitional pathways in modernizing energy markets.

At the earliest stages of urbanization or cities' development, when wood is extensively available, urban residents typically consume wood fuel to the exclusion of other fuels. This could be because traditional fuels can be supplied relatively economically or are a side effect of agricultural land conversion. As urban areas expand, however, the incentive to consume biofuels is moderated by a number of feedback effects. For example, Barnes et al. argued that the diminishing availability of biomass resources in the vicinity of cities would increase the harvest and transport costs of wood fuels as urbanization proceeds. They further argued that eventually, as urban areas expand, modern fuels will become more available and affordable by way of well-established networks. In this respect, rising incomes and rapid urbanization are seen as the crucial variables or drivers of the transition. In addition, they argued that it matters whether rising incomes are equitably distributed or not, in terms of whether the urban energy transition will be broadly based or not. Leach (1992) argued that relative fuel prices are of lesser importance and identified poor access to modern fuels and high cost of appliances as the main constraints of the transition from traditional to modern fuels.

2. Theoretical Models

Our study specifies a theoretical utility maximization model and a demand for electricity consistent with discrete appliance choice, following Dubin and McFadden (1984). Emphasis is given to electricity demand and the use of electric mitad cooking appliances because electricity substitutes well for fuelwood to bake injera. However—and more important—Ethiopia is one of the few African countries with an immense hydropower potential. If Ethiopia uses this energy source to make the transition from fuelwood to electricity, it could significantly reduce the pressure on local forests and gain positive environmental and health externalities.

Economic theory suggests that the demand for owning consumer durables arises from the flow of their services. The utility associated with a consumer durable is at best observed indirectly. Although durables may differ in capacity, efficiency, versatility, and corresponding prices, the consumer will ultimately utilize the appliance at an intensity level that provides the "necessary" service. Corresponding to this usage is the cost of the derived demand for the fuel that the durable consumes. The consumer must weigh each alternative appliance against expectations of future use, future energy prices, and current financing decisions in view of maximizing the utility.

Consider a consumer who faces a choice of m mutually exclusive, exhaustive cooking appliance portfolios, which can be indexed as $i = 1, \ldots, m$. Appliance portfolio i has a rental price, *ri*. Given appliance portfolio i, the consumer has a conditional indirect utility function (Dubin and McFadden, 1984):

$$u = V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta) \quad , \tag{1}$$

where p_1 is price of electricity, p_2 is price of alternative energy source (i.e., fuelwood), y is income, z_i is observed attributes of appliance portfolio i, $\in_i$ is unobserved attributes of portfolio i, r_i is price (cost) of appliance portfolio i, and η is unobserved characteristics of the consumer. Using Roy's identity (Mascolell et al. 1995), electricity and alternative energy (fuelwood) consumption levels, given appliance portfolio i, are given by:

$$x_1 = \frac{-\partial V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta) / \partial p_1}{\partial V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta) / \partial y} \text{ ; and} \tag{2}$$

$$x_2 = \frac{-\partial V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta) / \partial p_2}{\partial V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta) / \partial y} \ . \tag{3}$$

Hence, the probability that appliance portfolio i is chosen is given by:

$$\begin{aligned} P_i = \Pr ob\{(\in_1, \ldots, \in_m, \eta) : & V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta) \\ & > V(j, y - r_j, p_1, p_2, z_j, \in_j, \eta) \text{ for } j \neq i\} \ . \end{aligned} \tag{4}$$

Once the function V satisfies the necessary and sufficient conditions and properties of an indirect utility function, it can be used to construct the econometric model.

3. Econometric Model

This section describes our empirical framework—the discrete choice models employed in answering our research questions. In the study area, the electric mitad and the traditional clay enclosed Tigrai-type stove are the two major cooking appliances for baking injera. The clay

Tigrai-type stove is essentially a wood-burning stove. Although our interest lies in identifying the most important factors that determine the adoption of the electric mitad, the choice between the two appliances might not be independent, hence, the need to develop an empirical procedure that allows us to capture this interdependence.

The bivariate probit model is a joint model for two binary outcomes that generalizes the index function model from one latent variable to two latent variables. Let s be an indicator variable, with s_1, and s_2, indexing whether or not the household owns an electric mitad cooking appliance or a wood stove, respectively. Note that the indicator variables s_1 and s_2 assume the value 1 if the household owns the cooking appliance or stove in question, and 0 otherwise. Hence, following Cameron and Trivedi (2005) and Greene (2003), we define the unobserved latent variables as:

$$\begin{aligned} s_1^* &= x_1'\beta_1 + \varepsilon_1 \\ s_2^* &= x_2'\beta_2 + \varepsilon_2 \end{aligned}, \qquad (5)$$

where ε_1 and ε_2 are joint normal with:

$$\begin{aligned} &E[\varepsilon_1 \mid x_1, x_2] = E[\varepsilon_2 \mid x_1, x_2] = 0, \\ &Var[\varepsilon_1 \mid x_1, x_2] = Var[\varepsilon_2 \mid x_1, x_2] = 1, \\ &Cov[\varepsilon_1, \varepsilon_2 \mid x_1, x_2] = \rho. \end{aligned} \qquad (6)$$

Note that each latent variable in equation (5) is a function of some explanatory variable x_i, for i = 1, 2. Hence, it could be that the equations have the same or completely different explanatory variables (i.e., $x_1 = x_2$), or may contain some common variables *plus* some variables that appear only in one or other equation. Then, the bivariate probit model specifies the observed outcome as:

$$s_1 = \begin{cases} 1 \text{ if } s_1^* \rhd 0, \\ 0 \text{ if } s_1^* \leq 0, \end{cases} \qquad (7)$$

$$s_2 = \begin{cases} 1 \text{ if } s_2^* \rhd 0, \\ 0 \text{ if } s_2^* \leq 0, \end{cases}$$

Note that this model collapses to two separate probit models for s_1 and s_2 when the error correlation ρ = 0. However, the advantage of estimating them together as a system in a bivariate probit framework is an efficiency gain when $\rho \neq 0$.

When $\rho \neq 0$, we have the joint probability:

$$
\begin{aligned}
p_{11} &= \Pr[s_1 = 1, s_2 = 1] \\
&= \Pr[s_1^* \rhd 0, s_2^* \rhd 0] \\
&= \Pr[-\varepsilon_1 \lhd x'_1 \beta_1, -\varepsilon_2 \lhd x'_2 \beta_2] \ , \\
&= \Pr[\varepsilon_1 \lhd x'_1 \beta_1, \varepsilon_2 \lhd x'_2 \beta_2] \\
&= \Phi(x'_1 \beta_1, x'_2 \beta_2, \rho)
\end{aligned}
\qquad (8)
$$

where Φ is the standardized bivariate cumulative density function; x_is, for i = 1,2, are vectors of regressors; and β_i are vectors of parameters to be estimated.

Given the determinants of household *h*'s decision to consume a specific fuel good *F*, consider a decision involving a choice between consuming and not consuming. Note that the decision whether or not to consume a specific fuel good *F* (for example, wood) by household *h* essentially involves a choice between yes or no. Such dichotomous choices are best modeled as probit. Hence, the probit model is specified as:

$$\text{Prob}\ (q^*_{Fh}=1) = \text{Prob}\ (f_{Fh}(p_F, y_h, \boldsymbol{H}_h) + e_{Fh} > 0)\ , \qquad (9)$$

where q^*_{Fh} is equal to 1, if household *h* consumes fuel good *F*, and 0 otherwise; p_F, y_h, and $\boldsymbol{H}_h$, respectively, are the prices of related fuel goods, income, and characteristics vectors that apply to the household; and e_{Fh} is a residual term.

4. Description of the Study Area

In Tigrai, the most northern region of Ethiopia, traditional biofuels are the primary source of fuel for the majority of the urban population in the area. Table A1 in the appendix presents the pattern of energy consumption of urban households in Ethiopia, both for the country in general and the Tigrai region in particular. In Tigrai, in 1995, biofuels accounted for over 90 percent of fuel consumption of urban households. However, the share of traditional fuels declined by about 10 percent, whereas electricity consumption increased from 0.8 percent to 5.8 percent between 1995 and 2003 in its urban areas.

Baking injera and cooking sauce, soup, or stew account for the bulk of urban domestic fuel consumption in Ethiopia. Boiling water, making coffee, and other similar activities also require lighting a fire several times a day. In all settlement typologies, baking injera consumes the most fuelwood and accounts for about 60 percent of total household fuel consumption (Gebreegziabher 2004; RTPC 1998).

Electricity and petroleum products are the two most available modern fuel sources in Ethiopia. Of the petroleum products, kerosene and LPG provide both light and power in urban and rural areas. In cities and large towns, many households use kerosene for cooking. In medium and small towns, where there is no electricity supply, kerosene is most often used for lighting, and in rare cases for cooking.

Ethiopian Electric Power Corporation (EEPCO) is the major supplier of electricity, in addition to a few community and privately-owned systems. There are 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 isolated power-generating units operating with diesel. (Table A2 in the appendix shows the role of these two systems in the overall electrical power supply of the country.)

The overall electricity supply has increased by 37 percent in the last five years (table A2 in the appendix), with the main growth coming from the expansion of hydropower. On the user side, 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 energy consumption by urban households, and the current level of electrification is only about 14 percent (ADC 2003). By and large, lighting is the primary use of electricity in the domestic sector. Electricity for cooking is limited to very few households in the larger towns. This implies a persistent increase in the demand for fuelwood and growing pressure on local forests.

5. Sampling and Data Description

Cross-sectional data was collected from a stratified sample of 350 urban households. The 1994 Population and Housing Census (CSA 1995) identified 74 towns in Tigrai. These urban centers were stratified into four types: city, large town, medium town, and small town based on population size (table 1). A two-stage sampling technique was applied in selecting the sample households. First, sample towns were selected and then sample households were selected from these sample towns, such that every household had the same chance of being included in the sample. However, the choice of towns was not random. This procedure helped ensure that a town at the western tip of the region would not be selected, which would have been too expensive to include in the study, given time and budget limitations.

To get an idea of the current population and base the sampling on the population size, the population of the selected towns was projected for 2000 and 2003. Proportionate sampling based on the share of towns from the current population was applied. The details about sample towns and sample size by town are provided in table 2.

Table 1. Classification of Urban Centers into Settlement Typologies

Settlement typology	Criterion (population or number of inhabitants)
City	> 100×10^3
Large town	25 - 100×10^3
Medium town	5 - 25×10^3
Small town	< 5×10^3

Source: EESRC (1995)

Table 2. Description of Sample Towns and Sample Size by Town

Town		Population 2003 (projected)			% of total	Total sample	Sample size/ town
		Both sexes	*Male*	*Female*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7) = (5)*(6)
Mekelle	City	139292	65709	73583	0.558	300	167
Adigrat	Large town	53765	24933	28832	0.216	300	65
Wukro	Medium town	23596	10672	12924	0.095	300	28
Kuha	Medium town	14178	6230	7948	0.057	300	17
Adigudem	Medium town	9798	4450	5348	0.039	300	12
Hagereselam	Medium town	5704	2308	3396	0.023	300	7
Samre	Small town	3072	1338	1734	0.012	300	4
Total		*249,405*			*1.00*		*300*

A questionnaire was prepared and administered. Data pertaining to expenditures on food, nonfood-nonfuel needs, and different sources of fuel (firewood, charcoal, kerosene, electricity, etc.); income; and types of cooking appliance (stove) technologies were collected. In addition, information on fuel preferences, and reason(s) for not using a specific cooking appliance or stove type was also collected. Five people were trained to administer the survey and collect the data. (Table 3 contains a summary of the variables.) Although the questionnaire was designed to collect data on all possible fuel types and categories, none of the sample households used LPG and crop residues. In addition, only about 26 percent of households used dung, which is generally free for collection. Thus, our empirical analysis focused on four fuel types: firewood, charcoal, kerosene, and electricity. In general, expenditure on these fuels accounts for about 19 percent of a household's total budget.

Table 3. Summary Statistics of Variables Considered in the Analysis (n = 350), Year 2003

Variable	Mean	Std. dev.	Min.	Max.
Wood price (ETB/kg)	0.47	0.259	0.05	3.00
Dung price (ETB/kg)	0.32	0.121	0.02	0.57
Charcoal price (ETB/kg)	0.64	0.299	0.08	1.67
Kerosene price (ETB/liter)	2.36	0.389	1.00	5.00
Electricity price (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
Family size	4.925	2.196	1	10
Age of head	49	14	18	95
Education of head: % completing each grade				
Illiterate	39			
Grade 1–3	15			
Grade 4–6	18			
Grade 7–8	11			
Grade 9–11	5			
Grade 12 and above	12			
Employment type or occupation of head (percent)				
Self employed	69			
Public employee	16			
Private employee	15			
Use of particular fuel (percent)				
Wood	93			
Dung	26			

Charcoal	75
Kerosene	74
Electricity	80

: ETB = Ethiopian birr; currently US$ 1 = 10.868 birr. KWh = kilowatt hour;

Table 4 relates city and town sizes (population) and income with energy use, both in terms of per capita fuel consumption per year (in KgOE, or kilogram of oil equivalent), as well as fuel choice. The data suggests per capita fuelwood consumption is the greatest among households that do not use electricity and in areas where electricity is not available. Per capita kerosene consumption was the largest in the cities of Mekelle and Adigrat, and per capital electricity consumption was largest in Mekelle and Wukro. However, the data do not show any clear pattern whether in terms of increasing urbanization (as explained by city/town size) or rising income per capita as noted by fuel consumption or energy type transition.

Table 4. City/Town Size and Fuel Use in Seven Urban Centers in Tigrai, 2003

City/town	Population (000's)	Annual income (ETB/cap)	Fuel				
			Fuelwood	*Charcoal*	*Dung*	*Kerosene*	*Electricity*
Fuel consumption (KgOE per capita per year)							
Mekelle	139	1778.04	536.96	463.27	0.485	72.17	128.96
Adigrat	54	1391.12	198.04	165.45	8.301	69.07	50.08
Wukro	24	1500.56	131.64	219.08	1.279	47.53	122.39
Kuha	14	1576.50	604.12	349.47	5.115	23.69	65.25
Adigudem	10	1205.15	498.20	531.26	5.683	2.61	24.96
Samre	6	1412.52	906.91	237.94	1.332	19.59	0
Hagereselam	3	1358.52	921.20	296.72	2.084	41.17	0
Fuel choice (percentage)							
Mekelle	139	1778.04	85.95	76.03	12.39	61.16	98.35
Adigrat	54	1391.12	96.77	80.64	25.81	97.85	100.00
Wukro	24	1500.56	93.75	87.50	40.62	65.62	96.87
Kuha	14	1576.50	95.83	70.83	25.00	20.83	100.00
Adigudem	10	1205.15	91.66	75.00	75.00	16.67	100.00
Samre	6	1412.52	100.00	53.12	34.37	100.00	0
Hagereselam	3	1358.52	100.00	69.44	33.33	97.22	0

Source: Authors' survey results and calculations. Barnes et al. (2004) was used for conversion into KgOE (kilogram of oil equivalent).

6. Results and Discussion

The sample households used one of four types of wood-burning stoves or the electric mitad. The traditional clay enclosed (Tigrai-type) stove is the most commonly used stove in urban areas in Tigrai. Three other wood fuel type stoves are less favored: the open hearth stove with three stones (rarely used except for some beer breweries), and the *Tehesh* and *Mirte* stoves (limited use). A description of the different cooking stoves used by the sample households is provided in table 5.

Table 5. Description of Cooking Appliances/Injera Baking Stoves Used by Sample Households (n = 350)

Stove type	No. of households involved	Percent
Open hearth (three-stone stove)	2	0.57
Tigrai type (traditional clay enclosed)	324	92.57
Tehesh	4	1.14
Mirte	1	0.29
Electric mitad	71	20.29

The open hearth (three stone) stove is very inefficient—about 85–90 percent of the potential energy is wasted (Dunkerley et al. 1981; Gebreegziabher 2007), which implies increased demand for traditional or biofuels and increased pressure on local forests. Both Tehesh and Mirte are improved stove technologies, recently introduced to help with the growing fuel problem. A Tehesh stove is different from the traditional Tigrai-type stove in that it has a double wall with a baffle that permits smoke (and heat) to recycle before it escapes out the chimney. It also is insulated on the bottom. Tehesh stoves are assumed to add 22 percent in fuel savings, as compared to the single walled-Tigrai stove variants. The Mirte stove, the newest in cooking appliance technology, is a portable, easily assembled pumice-cement stove. Other things being constant, if households adopted improved wood stoves capable of a conversion efficiency of 20–30 percent, household consumption of fuelwood could drop by 50 percent (Gebreegziabher 2007).

In spite of the fact that about 80 percent of sample households used electricity, only about 20 percent had adopted the electric mitad. The high cost of the stove was the main reason for not adopting it, as cited by two-thirds of households using other stove types.

6.1 Electric Mitad Cooking Appliance Adoption

Among the sample households, electricity is mainly used for lighting, and wood still constitutes the major source of cooking fuel. A bivariate probit model was applied to determine the factors underlying the adoption of the electric mitad and the traditional Tigrai wood-burning stove. However, because the choice between the two appliances might not be independent, a bivariate probit model involving choices of the two cooking appliances was estimated. But before interpreting the results, we tested whether to reject the null hypothesis that the error correlation $\rho = 0$, in favor of the alternative that $\rho \neq 0$. The likelihood ratio test revealed that the error correlation was significantly different from zero at the 2-percent level, implying that we could not reject the alternative hypothesis.

The price of related goods; household income (expenditure); and other household characteristics, including family size plus age and education of the household head, were the explanatory variables considered. To control for any bias in terms of access to electricity or existence of the electric mitad appliance, a separate regression was run by including a dummy variable and excluding an urban center with no electricity. There was no significant change in the results. (Bivariate probit regression results for the full sample are presented in table 6.) All price variables turned out to be insignificant, contrary to what we expected, contradicting the main reason mentioned by households themselves for not using the electric mitad.

Characteristics of households, such as household income (expenditure), family size, and age and education of the household head, were positive and significant. They matter more in determining whether or not households adopt the electric mitad. On the other hand, of all the variables only household income (expenditure) was significant and negative in the case of wood stoves. This is good news in the sense that it suggests that fewer wood stoves will be adopted as incomes rise.

However, only one variable turned out to be significant and the efficiency gain in the bivariate estimation is important. As seen in table 6, the overall validity of the model holds. Considering the likelihood ratio test, for example, the computed value chi-square is greater than the critical value at better than a 1 percent level of significance, implying that the restrictions do not apply. Put differently, this supports the alternative hypothesis that all the explanatory variables together help explain the variation. The table also includes marginal effects of the joint probability of electric mitad cooking appliance and wood stove adoption. The results suggest that higher household incomes increase the likelihood of adopting the electric mitad. One year of extra schooling of the household head (all things the same) increases the joint probability of adoption by 0.022. Similarly, a unit change in family size and age of household head also implies an increase in the joint probability of adoption by 0.028 and 0.008, respectively.

Table 6. Bivariate Probit Estimates of Determinants of Electric Mitad and Wood Stove Adoption

Variable	Electric mitad coefficient	Wood stove	Marginal effects (joint probability)
Price of wood	0. 068 (0.503)	1.651 (10.612)	0.015 (0.111)
Price of charcoal	0. 152 (0.455)	4.506 (9.497)	0.034 (0.101)
Price of kerosene	-0.468 (0.415)	-1.216 (1.453)	-0.104 (0.091)
Household income/expenditure ('000 ETB†)	0.061*** (0.020)	-0.1624** (0.076)	0.014*** (0.000)
Family size	0.129** (0.056)	0.920 (0.776)	0.028** (0.012)
Age of head	0.036*** (0.011)	-0.048 (0.077)	0.008*** (0.002)
Education of head	0.101* (0.058)	-0.618 (0. 482)	0.022* (0.013)
Employment type/ occupation	0.059 (0.053)	-0.196 (0.681)	0.013 (0.012)
constant	-3.365*** (1.357)	7.211 (6.139)	
ρ	-1		
Log likelihood	-68.492		
Wald $\chi^2(16)$	40.50		
Prob > χ^2	0.001		

† ETB = Ethiopian birr.
Standard error is in parentheses.
***, **, and * indicate statistically significant at 1%, 5%, and 10% level (or better), respectively.

6.2 Factors Affecting Fuel Choice

The fuel-specific probit model estimates the determinants of fuel choice, such as the factors explaining a household's decision to consume a particular fuel. It offers insights into how the different sources of fuel relate to each other. Table 7 summarizes the individual probit regression results by fuel good.

In urban domestic energy consumption in Ethiopia, fuelwood, electricity, and dung are mainly used for injera baking, and charcoal and kerosene are mainly used for other cooking—and the cooking appliances or stove technologies for each are quite different. Hence, interdependencies may be expected among use of fuelwood, electricity, and dung, as well as between charcoal and kerosene. Consequently, we ran test regressions of three different models.

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

Table 7. Probit Model Results of Household's Fuel Choice (Dependent Variable Use of Particular Fuel)[a]

Regressor	Traditional biofuels		Modern fuels	
	Wood	*Charcoal*	*Kerosene*	*Electricity*
Price of wood				0.719**
Price of charcoal	-0.421		1.563***	3.194***
Price of kerosene	0.134	0.551**		
Price of electricity		0.185	1.803	
Household income/expenditure ('000 ETB)	-0.014	0.122***	0.139***	0.020
Family size	-0.018	-0.137**	-0.045	0.028
Age of head	0.004	0.023**	-0.018**	0.023**
Education of head[b]	-0.165***	-0.024	-0.064	0.172**
Employment type or occupation[c]	0.065	0.007	0.032	-0.084
Constant	1.816*	-1.343	-0.666	-2.626***

[a] This is a summary of individual probit regression by fuel good.

[b] Education of head (highest grade completed) defined as 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 no complete, 8 = Degree no complete, 9 = Diploma, 10 = Degree, and 11 = post graduate, respectively.

[c] Employment type or occupation was captured as 1 = self employed; 0 otherwise.

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

We considered household income (expenditure) and other household characteristics (such as employment type or occupation) as explanatory variables in the empirical analysis. Education of the head of household significantly and negatively influenced the decision to consume wood, but the rest of the variables had no significant effect. The price of kerosene positively and significantly influenced the decision to consume charcoal. Moreover, household income, family size, and age of household head also significantly influenced the decision to consume charcoal. An increase in the level of education of the head of the household by one unit (for instance, from grades 1–3 to grades 4–6) would on average reduce the probability of households consuming wood by 16.5 percent, all things staying the same. This implies that the higher the level of education, the less likely the household will use fuelwood.

A positive association between the price of kerosene and the decision to consume charcoal also suggests that charcoal and kerosene are substitutes. Similarly, price of charcoal positively and significantly influenced the decision to consume kerosene. In addition, household income and age of household head were found to be statistically significant. The price of wood, price of charcoal, and age and education of household head was significant and positive for consumption of electricity. The positive relation between price of wood and a household’s decision to consume electricity indicates that wood and electricity are also close substitutes.

Arnold et al. (2006) argued that charcoal remains a major source for the urban poor, implying it is the only substitute for fuelwood. However, our results reveal that charcoal and kerosene are substitutes, and that wood and electricity are also interchangeable. Moreover, our findings show the diversity of lifestyles[2] and end uses, or purposes, for which these fuels are used in the different local circumstances.

[2] The term lifestyle as used here means how people (individuals or in groups) live and how they cook, including their food habits.

7. Conclusions and Policy Implications

This paper investigated urban energy transition and new technology adoption as a way of reducing the pressure of urban centers on rural areas. A bivariate probit model was estimated to determine the factors underlying the use of electric mitad cooking appliances and wood stoves, and a household's choice of a specific fuel source In addition to prices of related goods, household income (expenditure) and other household characteristics (such as family size and age and education of household head) are important variables explaining household's choice of a particular fuel. Nonetheless, the relative importance of factors varied from one fuel source to the other. There was no difference, in terms of fuel source selection, whether the household head was self-employed or a public or private employee. Improvement in income and education enhanced the likelihood that a household would use electricity and reduce its consumption of wood, implying a reduction in pressure on wood resources. Moreover, probit regression results on household's fuel choice suggested that charcoal and kerosene, as well as wood and electricity, are substitutes.

The results of this paper have the following implications. Raising the level of education and income of households will enhance the use of electricity and electric mitad adoption and reduce wood consumption. Thus, policy interventions in this regard would help to facilitate the energy transition from fuelwood to electricity through widespread use of more efficient cooking appliances and thus reduces the pressure of urban centers on their rural hinterlands and the resulting deforestation.

Evidence in this paper, which suggests a growing role of modern fuels, such as electricity and kerosene, and a declining role of dung and charcoal, however, does not support the energy ladder hypothesis.

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Appendix

Table A1. Final Energy Consumption of Urban Households in Ethiopia: Country Overall and Tigrai

Fuel type	Country overall (1998–1999)		Urban Tigrai (1995)	Urban Tigrai (2003)*	
	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
Briquette 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*

* Authors' survey results for representative household and RWEDP (1997) were used for conversion into energy units.

Source: ADC (2003) and EESRC (1995)

Table A2. Energy/Electricity Production (Country Overall) by System/Source and Year (in GWh)

System/source	Year						
	1999–2000	*2000–2001*	*2001–2002*	*2002–2003*	*2003–2004*	*2004–2005*	*2005–2006*
ICS							
Hydro	1,631.5	1,774.3	1,975.2	2,007.1	2,262.5	2,521	2,832
Diesel	4.0	2.1	0.1	21.1	16.1	18.4	12
Geothermal	20.0	5.1	1.0	0.0	0.0	0.0	0
Total	1,655.5	1,781.5	1,976.3	2,028.2	2,278.6	2,539.6	2,844
SCS							
Hydro	14.3	15.5	16.6	16.5	16.5	17.9	19
Diesel	19.0	14.8	16.5	19.0	22.7	31.1	32
Total	33.3	30.3	33.1	35.5	39.2	49.0	51.0
ICS+SCS							
Hydro	1,645.8	1,789.8	1,991.8	2,023.6	2,279.0	2,539.1	2,851.0
Diesel	23.0	16.9	16.6	40.1	38.8	49.5	44.0
Geothermal	20.0	5.1	1.0	0.0	0.0	0.0	0.0
Total	1,688.8	1,811.8	2,009.4	2,063.7	2,317.8	2,588.6	2,895.0

Note: GWh = gigawatt hour.

Source: http://www.eepco.gov.et/

Table A3. Indigenous Alternative Energy Resources in Ethiopia

	Unit	Total reserve	Exploitable reserve	Exploited (%)
Hydro power	MW		>45,000	3
Solar energy	kWh/m^2		7,466,232	~0.1
Wind energy	Tera-joules/year		18,049,000	5
Geothermal	MW	700	700	1.2
Coal	Million metric tons	78	14	0
Natural gas	Trillion m^3	4.1	4.1	0
Bagasse	MW		119	0

Notes: MW = megawatt; kWh = kilowatt hour.

Source: Hassen (2008)