Household Fuel Choice in Urban Ethiopia

A Random Effects Multinomial Logit Analysis

Yonas Alem, Abebe D. Beyene, Gunnar Köhlin, and Alemu Mekonnen

EfD
Environment for Development

RESOURCES
FOR THE FUTURE

Environment for Development

The **Environment for Development** (EfD) initiative is an environmental economics program focused on international research collaboration, policy advice, and academic training. It supports centers in Central America, China, Ethiopia, Kenya, South Africa, and Tanzania, in partnership with the Environmental Economics Unit at the University of Gothenburg in Sweden and Resources for the Future in Washington, DC. Financial support for the program is provided by the Swedish International Development Cooperation Agency (Sida). Read more about the program at www.efdinitiative.org or contact info@efdinitiative.org.

Central America
Research Program in Economics and Environment for Development
in Central America
Tropical Agricultural Research and Higher Education Center (CATIE)
Email: efd@catie.ac.cr

China
Environmental Economics Program in China (EEPC)
Peking University
Email: EEPC@pku.edu.cn

Ethiopia
Environmental Economics Policy Forum for Ethiopia (EEPFE)
Ethiopian Development Research Institute (EDRI/AAU)
Email: eepfe@ethionet.et

Kenya
Environment for Development Kenya
Kenya Institute for Public Policy Research and Analysis (KIPPRA)
University of Nairobi
Email: kenya@efdinitiative.org

South Africa
Environmental Economics Policy Research Unit (EPRU)
University of Cape Town
Email: southafrica@efdinitiative.org

Tanzania
Environment for Development Tanzania
University of Dar es Salaam
Email: tanzania@efdinitiative.org

Household Fuel Choice in Urban Ethiopia: A Random Effects Multinomial Logit Analysis

Yonas Alem, Abebe D. Beyene, Gunnar Köhlin, and Alemu Mekonnen

Abstract

We use three rounds of a rich panel data set to investigate the determinants of household fuel choice and energy transition in urban Ethiopia. We observe that energy transition did not occur following economic growth in Ethiopia during the past decade. Regression results from a random effects multinomial logit model, which controls for unobserved household heterogeneity, show that households' economic status, price of alternative energy sources, and education are important determinants of fuel choice in urban Ethiopia. The results also suggest the use of multiple fuels, or "fuel stacking behavior." We argue that policy makers could target these variables to encourage transition to cleaner energy sources.

Key Words: urban Ethiopia, energy choice, random effects multinomial logit

JEL Codes: C25, Q23, Q42, O13

Contents

Household Fuel Choice in Urban Ethiopia: A Random Effects Multinomial Logit Analysis

Yonas Alem, Abebe D. Beyene, Gunnar Köhlin, and Alemu Mekonnen*

Introduction

Although urbanization and increased per capita income usually result in greater use of modern fuels, such as gas and electricity and a fall in the share of traditional biomass (IEA, 2004), this has not happened in many African cities (Chambwera and Folmer, 2007) including those in Ethiopia. Although Ethiopia is endowed with a variety of clean energy sources, such as hydropower, geothermal, wind, and solar energy, both rural and urban Ethiopian households rely heavily on biomass fuel for their energy needs. Data for the year 2009 show that only 8 percent of the total energy consumption in Ethiopia came from modern fuels (MoWE, 2011). The heavy reliance on biomass fuels has been one of the prime causes of forest degradation and deforestation in Africa in general and Ethiopia in particular (World Growth, 2009).

Extreme poverty and lack of access to other fuels contribute to the heavy dependence of the population of sub-Saharan Africa on traditional fuels (IEA, 2002). A better understanding of the different factors that hinder the transition to modern fuels will help to design interventions by both governmental and nongovernmental organizations working on energy and energy related issues.

In spite of the importance of household energy in most developing countries, rigorous empirical studies on the factors affecting household preferences and choice of domestic energy are limited but growing. Existing studies on adoption of clean energy sources by households in developing countries remain scattered and largely qualitative; rigorous statistical analysis on households' fuel choice is rare (Lewis and Pattanayak, 2012). Previous studies such as Heltberg (2005), Gupta and Köhlin (2006), and Gebreegziabher et al. (2012) addressed the issue of

household fuel choice for different fuel types by urban households in developing countries. However, all used cross-sectional data which do not examine the dynamic aspect of household energy choice. A particular area of recent research interest is the issue of whether households reveal fuel stacking behavior (the use of multiple fuels). This has not been carefully examined, especially in Africa (Masera et al., 2000). Mekonnen and Kohlin (2008) attempted to do this for Ethiopia using only two of the three rounds of the dataset used in this paper. Moreover, their analysis was based on a pooled multinomial logit model which does not control for unobserved household heterogeneity and suffers from the independence of irrelevant alternatives (IIA) property.

In this paper, we attempt to examine the presence of fuel stacking behavior and understand various socioeconomic factors that determine household fuel choice in urban Ethiopia using three rounds of panel data. Using panel data analysis we also control for unobserved household heterogeneity. The data was collected from 2000 to 2009, which corresponds to significant changes in major macroeconomic variables in Ethiopia such as inflation. According to the World Bank report, the inflation rate during our study period (2000-2009) ranged from -8.2 to 44.4 percent, with the lowest in 2001 and the highest in 2008.[1] Hence, it is interesting to see whether there is any change in the behavior of households towards their fuel choices. Our approach is also different from most other studies on the topic as we are looking at the issues of energy transition and energy ladder by classifying energy into solid, mixed and clean fuels using multinomial random effects logit analysis. The study also contributes to the limited but growing empirical evidence on household energy choice in African nations, such as Ethiopia.

The questions this study attempts to answer include: what are the socioeconomic factors that determine households' fuel choice in urban Ethiopia? How does the pattern of energy consumption in urban households change over time and across income groups? Regression results from a random effects multinomial logit model, which controls for unobserved household heterogeneity, show that households' economic status, price of alternative energy sources, and education are important determinants of fuel choice in urban Ethiopia. Moreover, the results suggest decreased likelihood of households to use clean fuels as their main cooking energy sources over time in favor of mixed fuels, suggesting fuel stacking over time. An increase in the

---

[1] The data can be accessed: http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG.

number of fuel types used by households as incomes rise also suggests the presence of fuel stacking. A clear understanding of the behavior of households towards fuel choice will help in the design of appropriate policies and programs that aim to alleviate energy poverty, as well as to reduce environmental problems, including deforestation and health problems associated with indoor air pollution. We argue that policy makers could target these variables to encourage transition to cleaner energy sources.

The paper is organized as follows. The second section presents background on the importance of energy choices in the developing world and a brief review of empirical studies. The third section presents the data used for this study, descriptive analysis, and the pattern of energy choice of sample households in urban Ethiopia. The fourth section specifies the empirical strategy employed for the analysis of household fuel choice in urban Ethiopia. The fifth section discusses the results. The last section presents conclusions and policy implications.

Background and Review of Empirical Studies

Background

Energy services are an essential input to economic and social development. Several reports prepared by international organizations have indicated that universal access to modern energy services is a must for the realization of the MDGs (OECD/IEA, 2010). This is because clean, efficient, affordable and reliable energy services are necessary to reduce poverty, improve the health of citizens, promote gender equality and enhance sustainable management of natural resources.

However, people in most developing countries are highly dependent on traditional sources of energy for cooking, heating and lighting which have negative impacts on health and the environment. It is estimated that over 700 million people in the Least Developed Countries (LDCs) and over 600 million in sub-Saharan Africa are without access to modern fuels for cooking (UNDP/WHO, 2009; IEA, 2005). While the problem is more serious in rural parts of Africa, only 42% of the urban people have access to modern fuels (UNDP/WHO, 2009) compared to 70% in urban areas of developing countries as a whole. This has also greatly contributed to the health and environmental problems of many developing countries. For example, according to estimates of the World Health Organization, more than 1.45 million people die prematurely each year because of exposure to indoor air pollution from biomass (OECD/IEA, 2010). The environmental impact can easily be seen by looking at the extent of fuel wood consumption for cooking. Africa has the highest per capita fuel wood consumption in the

world (0.89 m^3/year) suggesting that the associated deforestation and forest degradation is likely to continue in the foreseeable future (Chambwera and Folmer, 2007).

Both governmental and nongovernmental organizations in many developing countries, including Ethiopia, have been trying to address the heavy dependence on biomass fuels by adopting different strategies, including the promotion of inter-fuel substitution for increased use of modern fuels and improved stoves (Heltberg, 2005). Two main reasons for this are: (i) a shift to modern energy sources will reduce pressure on forests, and (ii) the use of traditional fuels has local environmental impacts such as outdoor smoke, smog and indoor air pollution. Moreover, the use of dung and crop residues as a source of energy has contributed to the decline in agricultural productivity (IEA, 2004). Increased scarcity of biomass fuels would also affect women and children, in particular, who would need to spend more time to collect these fuels; time which could have been spent on other activities such as agriculture and education. In general, use of modern energy services will improve the welfare of households in many ways (Heltberg, 2005). For example, a number of documents indicate that by extending the day, access to electric light provides extra hours for reading and hence helps improve the school performance of children. For men and women working in and outside the home, it also extends working hours. Clean cook-stoves can reduce fuel consumption and the negative health effects of 'dirty' fuels, especially on women and children, from daily exposure to noxious cooking fumes. In sum, improved access to modern energy can contribute to poverty reduction and development targets of a developing country by raising its productivity and allowing production of a variety of goods and services.

A Brief Review of Empirical Studies and Implications

In this section we briefly review energy studies conducted at the household level in developing countries focusing on rigorous studies on energy choice. The limited but growing rigorous empirical literature on energy choice provides limited information on the variables that affect the fuel choice and switching behavior of households (Heltberg, 2004). As noted by Heltberg (2005), household fuel choice in the past has often been analyzed and understood through the lens of the energy ladder model. The central idea of the energy ladder hypothesis is that households will shift to the use of modern energy sources like kerosene and electricity as their income increases. Based on this, most empirical studies tend to agree that income is a key determinant of total energy demand, although it can be difficult to interpret and compare these studies due to different measures of income they use. However, several researchers question the energy ladder hypothesis, because fuel use decisions are influenced by several other social and

economic factors (Masera et al., 2000). According to Heltberg (2005) and Mekonnen and Kohlin (2008) household income is an important, but not the only, factor. Modern fuels are often used alongside traditional solid fuels, particularly in rural areas and a large proportion of urban residents. Evidence from urban Ethiopia, using panel data collected in the years 2000 and 2004,[2] indicates that multiple fuel use better describes fuel-choice of households (Mekonnen and Kohlin, 2008). Further, Mekonnen and Kohlin (2008) conclude that fuel types such as wood are not considered inferior goods by urban households in Ethiopia. In sum, studies suggest that fuel availability, affordability and cultural preferences are main determinants in the transition from traditional to modern energy use (IEA, 2002). This supports the limited but growing evidence showing that multiple fuel use, or what Dewees (1989) called 'fuel stacking,' is widespread in many developing countries (Heltberg, 2004).

Several studies emphasize the use of multiple fuels for various reasons. Use of multiple fuels provides a sense of energy security. This is because complete dependence on a single fuel or technology may make households vulnerable to price variations and unreliable service (OECD/IEA, 2006). Another reason could be due to preferences and familiarity with cooking using traditional technologies. In India and several other countries, for example, many wealthy households retain a wood stove for baking traditional breads. Similarly, Ouedraogo (2006) finds that wood energy remains the preferred fuel of most urban households of Burkina Faso. This suggests that an increase in income may increase the number of fuel types used due to increased capacity to use different types of cooking equipment.

The literature on energy choice shows that households' characteristics affect the choice of fuels in developing countries. Almost all studies find that household size is a key determinant of fuel choice. Ouedraogo (2006) indicated that household size is one of the sociological, demographic and cultural variables which have a significant effect on wood-energy preferences. For example, low household size is strongly related to the adoption of LPG for cooking but a decrease in firewood adoption. A large household size with many females translates into low opportunity costs of collecting and using firewood, and therefore often leads to fuel stacking. Similar conclusions were reached by other studies, such as Narasimha and Reddy (2007). Heltberg (2004) analyzed the determinants of fuel switching using comparable household survey

---

[2] This data is the same as the one used for this paper except that the current study includes an additional wave collected in 2009.

data from Brazil, Ghana, Guatemala, India, Nepal, Nicaragua, South Africa, and Vietnam. His results show that household size affects fuel choice but does not trigger fuel switch. He argued that larger households are more likely to consume multiple fuels, both solid and non-solid. Education is also another important household characteristic that has been included in related studies on energy demand. A study by Narasimha and Reddy (2007) in India, Jiang and O'Neill (2004) in rural China, Mekonnen and Kohlin (2008) in urban Ethiopia and Heltberg (2004; 2005) are some of the examples which underline the importance of education or awareness in reducing the demand for traditional fuels such as firewood. According to Heltberg (2004), education, in addition to other factors accompanying development, such as urbanization and electrification, can contribute to the process of fuel switching. Chambwera and Folmer (2007) note that education can be considered as a long term policy to handle and manage the demand for firewood. Mekonnen and Kohlin (2008) also argue that education may help to understand the negative effects of biomass on health and increase the opportunity cost of time.

Gupta and Kohlin (2006) argue that availability and ease of use are very important for the choice of fuel. Fuel choice is also correlated with other variables such as ethnicity and region of residence. For example, Narasimha and Reddy (2007) examine the fuel choice decision of households separately for rural and urban households of India and find that the factors that affect fuel choice are entirely different in the two areas.

Due to data limitations, most studies do not include prices in their energy choice analysis. Moreover, as described earlier, access is often a constraint for households' fuel choice decision. Both price and accessibility can be important variables for design of policies with regard to household energy. As Barnes et al. (2004) note, governments can influence fuel utilization of households by using these two channels (price and accessibility). Ouedraogo (2006) argues that a price subsidy for liquefied petroleum gas (LPG) and its cook stoves could significantly decrease the utilization rate of wood-energy. Similarly, Gupta and Kohlin (2006) note that increasing the price of fuel wood and increasing LPG availability are important factors if the policy objective is to reduce indoor air pollution.

In general, increased use of modern fuels and improved wood-stoves can play a significant role in reducing the burden on women and child mortality as well as improving maternal health, children's schooling and agricultural productivity. It would also help reduce deforestation and forest degradation associated with biomass fuel use. However, energy consumption in Africa is highly dominated by traditional energy sources such as fuel wood, charcoal, dung and crop residues. While the use of modern fuels is relatively more common in urban areas, a significant proportion of urban households in Africa are still dependent on

traditional energy sources for their cooking, heating and lighting requirements. A country's relative poverty, degree of urbanization and availability of other substitute fuels are important in influencing consumption of traditional energy sources in a country (IEA, 2002).

We may conclude that the available empirical studies on energy choice use different approaches (e.g., qualitative, descriptive and econometric approaches) and reach different conclusions regarding the factors that affect households' choice of cooking fuels. This is supported by a recent systematic review by Lewis and Pattanayak (2012) who find that the effect of some variables such as fuel availability, fuel prices, household size, and sex is still unclear. We also note from our review that rigorous empirical studies on household energy choice in Africa are growing but still limited and more studies are required to better understand the energy choice and consumption behavior of African households. Use of panel data in such studies is even more limited and this study contributes to the literature by applying panel data techniques which, among others, control for unobserved household heterogeneity.

Data, Descriptive Analysis and Patterns of Household Energy Consumption in Major Cities in Ethiopia

Data

In this study we use three rounds of the Ethiopian Urban Socio-economic Survey (EUSS) - a panel data set collected in 2000, 2004, and 2009. EUSS is a rich data set containing several socio-economic variables at the individual and household level. The first two waves of the data used in this paper were collected by the Department of Economics of Addis Ababa University in collaboration with the University of Gothenburg, and covered seven of the country's major cities - the capital Addis Ababa, Awassa, Bahir Dar, Dessie, Dire Dawa, Jimma, and Mekelle.[3] The cities were believed to represent the major socioeconomic characteristics of the Ethiopian urban population at the time. Originally, a total sample of about 1,500 households was distributed over these urban areas proportional to their population. Once the sample size for each urban center had been set this way, households were recruited from all woredas (districts) in each urban center. More exactly, households were selected randomly from half of the kebeles (the lowest administrative units) in each woreda, using the list of residents available at the urban

---

[3] Data were also collected in 1994, 1995, and 1997 but did not contain information on household energy use.

administrative units. An additional survey was conducted by one of the authors in late 2008 and early 2009 comprising 709 households from a sub-sample of the original sample covering the four cities Addis Ababa, Awassa, Dessie, and Mekelle. The cities were carefully selected to represent major urban areas of the country and the original sample.[4] All the panel households in the cities of Awassa, Dessie, and Mekelle, and about 350 of the original households in Addis Ababa were selected following the sampling procedure discussed in the preceding paragraph. Out of the total 709 households surveyed in 2009, 128 were new households randomly included in the survey. The new households were incorporated in the sampling to address the concern that the group of panel households, since they were formed back in 1994, may not represent the current Ethiopian urban population. As shown by Alem and Soderbom (2012), there was no significant difference in economic status as measured by consumption expenditure between the old and the new households, conditional on observable household socio-economic characteristics. This gave us the confidence to believe that the sample represents urban Ethiopia reasonably well. The panel data set contains information on household living conditions including income, expenditure, demographics, health, educational status, occupation, production activities, asset ownership, and other variables at household and individual levels. New sections on shocks and coping mechanisms, government support, and institutions were included in the most recent survey. In our analysis, we use all the households surveyed in the three waves in all the four cities comprising 2917 observations.

Descriptive Statistics

Table 1 presents the definition and descriptive statistics of variables used in the empirical analysis. Most of the sample households (71%) are located in Addis. In terms of fuel choice, the data show that more than 46% of the sample households use electricity, gas and kerosene as their main energy source for cooking (which are categorized as 'clean energy sources' in this study).[5] The other categories used in this study are mixed and solid fuels. The category 'solid fuel' refers to biomass energy sources such as firewood, charcoal, dung and crop residues. The term 'mixed fuels' refers to a combination of clean and solid fuels. The proportion of sample households who depend on mixed (solid and non-solid) energy and solid energy as main energy sources is 27.2%

---

[4] Due to resource constraints, we were not able to cover other cities in the sample.

[5] 'Clean energy' and 'modern energy' are used interchangeably throughout this paper.

and 26.4%, respectively. Around 54% of the household heads are male. The level of education for more than 74% of the household heads, was primary school or higher. The descriptive statistics by year are presented in Appendix A.

Figure 1 shows the proportion of sample households using clean, mixed and solid fuels as their main fuels by survey year. It is clear from Figure 1 that there is a decline in the proportion of households whose main cooking energy is clean (51.05%, 47.9% and 37.9% for year 2000, 2004 and 2009, respectively). On the other hand, the proportion of households with mixed fuels as the main cooking energy slightly increased (25.3%, 27.4%, and 29.9% for year 2000, 2004 and 2009, respectively). Similar to mixed fuels, there is an increase in the proportion of households using solid fuels as their main cooking energy over the three survey years.

Figure 2 presents the proportion of sample households by specific energy type used. The fuel types included are electricity, firewood, charcoal, kerosene, LPG, crop residues, twigs and dung. Other fuel sources not included in the figure because of a small proportion of households that use them include leaves, wood residue, and biogas.

As shown in Figure 2, the proportion of households using electricity for cooking increased consistently over the three survey years with the increase from 2000 to 2004 being smaller than that from 2004 to 2009. Over a period of about a decade (2000 to 2009), the proportion increased by more than 8%. On the other hand, the proportion of households using firewood declined from 22% in 2000 to 17% in 2004 and then remained the same in 2009 (16.8%). In 2004, the proportion of households using non-wood biomass energy sources such as dung cakes, twigs and branches, leaves, and crop residues was higher compared to the years 2000 and 2009. The proportion of households using modern fuel sources decreased from 25% in 2000 to 18.6% in 2004 and then increased to 20.5% in 2009. On the other hand, the proportion of households who used LPG increased in 2004 compared with the year 2000, but in 2009 it decreased back to its level in the year 2000.

It is also interesting to see how Figures 1 and 2 compare. A simple and direct comparison of Figures 1 and 2 is not easy as the former refers to groups of energy types, as well as the main cooking fuel used, while the latter refers to specific energy types and whether or not the household used an energy type. Thus, for example, Figure 1 shows that the proportion of households who used clean fuels (which includes electricity) has decreased over time. On the other hand, Figure 2 shows the proportion of households who used electricity has increased over

time. These suggest that while there is an expansion in terms of access to electricity, households are using less electricity and other clean fuels over time as their main cooking fuels.[6]

Figure 3 shows the average number of different fuels that households used by per adult equivalent real monthly expenditure.[7] This figure provides information on whether, and in what direction, the number of fuel types used by households changes as per adult equivalent monthly expenditure changes; this would, in turn, have implications for the presence of 'fuel stacking' behavior. The energy types included in Figure 3 are electricity, charcoal, kerosene, firewood and LPG. It can be seen that the average number of fuels used by each of the 25 expenditure categories (groups) is between 2.36 and 3.69, where each category represents more or less the same number of households. The graphs for each year, as well as for the whole study period, are more or less similar, showing that the behavior of households with respect to the number of fuel types used did not change much during the study period. At lower levels of per capita real consumption expenditure, households tend to increase the number of fuels they use as their per capita real consumption expenditure increases; then after some level of consumption expenditure, the average number of fuels used remains more or less constant as real per capita consumption expenditure of households' increases. This suggests the presence of 'fuel stacking' behavior. As argued by Mekonnen and Kohlin (2008), this might be because as households' income increases, they can afford to buy additional stoves and to use a fuel type not used before if required for the new stoves. Beyene and Koch (2012) also find that the adoption of improved stoves increases with household's income. The demand for different stoves/fuel types may be explained by factors such as uncertainty about the supply of a fuel type, preferences for a particular type of fuel, convenience of the specific fuel type, etc.

The pattern of energy use by city shows that clean, mixed, and solid energy types are used in all cities covered by this study. But the proportion of households who depend on the particular fuel category differs across cities. In particular, more than 52% of the sample

---

[6] Note that clean fuels also include kerosene and diesel. Over the three survey years, we note from Figure 2 that use of kerosene and diesel declined in 2004 and increased slightly in 2009 compared with 2000.

[7] In order to take into account differences in consumption needs between children and adults in the household, total household consumption is adjusted by using adult equivalence scale. Note also that both price and expenditure are expressed in real terms and adjusted for spatial and temporal price differences.

households in Addis Ababa depended on clean fuels for cooking in the year 2000. This proportion increased to about 56% in 2009. All other cities in our sample have a smaller proportion of households who depend on clean fuels for cooking compared with Addis Ababa. Another related but interesting aspect is the decline in the proportion of households who depend on firewood for cooking in Addis (16.4%, 13.5% and 11% in 2000, 2004, and 2009, respectively). These percentages are higher for the other cities in our sample. While the reasons for differences need to be examined more carefully, we may note that this may be due to differences in the availability of fuels and differences in the awareness of households, with respect to the importance of modern energy sources in terms of health and other environmental effects. This suggests the need to consider differences across cities or regions in analyses of energy choice. The empirical analysis presented in the next section discusses the extent and direction of the effect of each explanatory variable on the choice of fuel by households while controlling for other variables.

We use a panel multinomial logit model with random effects to model household fuel choice in urban Ethiopia. Let the utility for household i from fuel type j(clean fuel only, a mix of clean and solid fuels, and solid fuel only, indexed j = 1, 2, 3) in time t(t = 1, 2, 3) be expressed as

$$V_{ijt} = X'_{it}\beta_j + \alpha_{ij} + \varepsilon_{ijt} \quad (1)$$

where X'_{it} is a vector of explanatory variables, the ε_{ijt} are time varying i.i.d. error terms while α_{ij} is a household and fuel type-specific time-invariant effect. The vector β_j is the coefficient for the vector of explanatory variables. The household chooses the fuel type for which utility is highest. With the assumption that ε_{ijt} follows a Type I extreme value distribution, the probability of choosing fuel type j at time t conditional on X_{it} and α_{ij} takes the multinomial logit form:

$$P\left(j,t/X_{it},\alpha_{i1,}\alpha_{i2}\right) = \frac{exp\left(X'_{it}\beta_J + \alpha_{ij}\right)}{\sum_{s=0}^{2} exp\left(X'_{it}\beta_s + \alpha_{is}\right)} \quad (2)$$

Because the choice probabilities are conditioned on αi, one must integrate over the distribution of the unobserved heterogeneity. Consequently, the sample likelihood for the multinomial logit with random intercepts can be given by:

$$L = \prod_{i=1}^{N} \int_{-\infty}^{\infty} \prod_{t=1}^{T} \prod_{J=1}^{J} \left\{ \frac{exp\left(X_{it}'\beta_j + \alpha_{ij}\right)}{\sum_{s=0}^{2} exp\left(X_{it}'\beta_s + \alpha_{is}\right)} \right\} d_{ijt} f(\alpha) d\alpha \ (3)$$

where $d_{ijt} = 1$ if household *I* chooses alternative *j* at time *t* and zero otherwise. For identification, α_{i1} and β_{i1} are normalized to zero; i.e., we make clean-fuel-only the base case. For convenience, it is also assumed that α is identically and independently distributed over the households and follows a multivariate normal distribution with mean *a* and variance-covariance matrix **W**, α~ f (a,W). In addition, as is the case in any random effects model, αis assumed to be independent of the explanatory variables X_{it}.

Maximization of the sample likelihood presented in [3] requires integrating over α. As there is no analytical solution for the integral, one can use either approximation methods such as Gauss-Hermite quadrature (Butler and Mofit, 1982), or adaptive quadratures (Rabe-Hesketh et al., 2002), or simulated maximum likelihood method (Haan and Uhlendorff, 2006). Rabe-Hesketh et al. (2002) show that adaptive quadrature is often computationally more efficient. We use their approach and estimate the multinomial logit model with unobserved heterogeneity using the Stata program "gllamm."

The MNL coefficients are difficult to interpret, and associating β_j with the jth outcome is tempting and misleading. To interpret the effects of explanatory variables on the probabilities, marginal effects are usually derived as (Greene, 2003):

$$\delta_j = \frac{\partial P_j}{\partial x_i} = P_j \left[\beta_j - \sum_{k=0}^{J} P_k \beta_k \right] = P_j \left[\beta_j - \overline{\beta} \right]$$

The marginal effects measure the expected change in probability of a particular choice being made with respect to a unit change in an explanatory variable (Greene, 2003).

Results

Regression results for determinants of household cooking energy choice in urban Ethiopia are presented in Tables 2 and 3. The regression results from a pooled multinomial logit model which does not control for unobserved household heterogeneity are presented in appendix B. While Table 2 shows the estimated coefficients, Table 3 presents marginal effects of results from a random-effects multinomial logit model controlling for unobserved household heterogeneity. As expected, the statistical test performed favors the random effects multinomial

logit model, which also relaxes the Independence of Irrelevant Alternatives (IIA) assumption (Glick and Sahn, 2005) and we use results from this model to analyze determinants of household energy choice in urban Ethiopia.

As we can see from the estimation results in Tables 2 and 3, several factors affect the choice of a category of energy source by urban households in Ethiopia. As expected, fuel prices are important determinants of fuel choice. As the price of firewood increases, the demand for solid and mixed fuels decreases. In other words, households tend to shift to clean fuel sources, such as electricity and kerosene, when firewood price increases. In particular, a 10 percent increase in price of firewood will increase the probability of using clean energy sources by 0.83 percent and reduce the probability of choosing solid fuels by 0.84 percent. That means increasing the price and reducing the availability of firewood may promote fuel switching by urban households. Price of electricity has a positive and significant effect on the choice of mixed fuels, while it is positive but not significant in the case of solid fuels. This may show that households do not completely switch back to solid fuels as price of electricity increases, but they try to minimize the budget burden by reducing part of their electricity consumption and satisfy the rest from solid fuels. An increase in kerosene price has a positive and significant effect on the choice of solid fuels but is not significant in the case of mixed fuels. A 10 percent increase in price of kerosene will increase the probability of using solid fuels by 2.96 percent and decrease the use of clean energy by 1.6 percent. The implication here is that an increase in the price of kerosene may worsen the health and environmental degradation problems as households tend to consume more biomass fuels. This suggests the need for a policy that targets the poor to compensate for the price increase. A price subsidy policy for kerosene may be one of those policy instruments to reduce the consumption of solid fuels such as firewood and charcoal and increase the choice of other energy sources such as kerosene. However, as argued by Kebede et al. (2002), the effect of a kerosene subsidy, even on the poor, is very minimal and non-poor households capture most of the subsidies in Ethiopia. It is also argued that designing and implementing subsidies for liquid fuels targeting the poor is difficult, because liquid fuels tend to be used more by the rich than by the poor (Bacon et al., 2010). Hence, there is a need for strategies that target the poorest segment of the population. These results suggest that fuel price can be considered as one of the instruments to influence energy choice of urban households in Ethiopia.

Consistent with the theory, higher per capita expenditure (which is a proxy for per capita income) is associated with a significant move away from solid fuels to clean fuels. As argued in the literature, income is one of the main determinants that affect fuel switching- from lower quality energy sources to higher quality energy sources (Leach, 1992). The literature shows that

some households tend to switch to a multiple fuel-use strategy (fuel stacking) as their incomes rise for a number of reasons. This suggests that policy makers should think in terms of encouraging fuel substitution by, for example, reducing prices of modern fuel sources and adopting other pro-poor strategies.

Our estimation results also show that several other variables are important determinants of fuel choice in urban Ethiopia. For example, education is a strong determinant of fuel switching. The higher the education level, the larger the probability of using clean fuel sources and the smaller the chance of using solid fuels such as firewood and charcoal. There are two possible explanations for this. First, education increases the opportunity cost of fuel wood collection time. Second, it could help improve awareness about the negative effects of biomass fuels on health (Mekonnen and Kohlin, 2008). Therefore, as argued by other studies on energy demand, education can be used as a long-term policy to shift household fuel use from traditional biomass to cleaner cooking fuels (Chambwera and Folmer, 2007).

Of the household characteristics, the number of children has a positive and significant effect on choice of solid fuels, which is generally not expected. This may be because households with more children have more child labor to collect firewood. Household size affects fuel choice, but it seems that larger households are more likely to consume multiple fuels including solid and non-solid (Heltberg, 2004). Share of females in the household is negatively and significantly related to the probability of choosing mixed fuels, but has no significant effect on choice of solid fuels. This result is not expected given that collection of biomass fuels often absorbs a significant amount of women's time and may have a much greater negative effect on their health as combustion of such traditional fuels may cause indoor air pollution.

The dummy variables for cities indicate that both solid fuels and mixed fuels are less likely to be chosen in Addis Ababa, relative to Mekelle, which is the base category. Moreover, compared to the base year 2000, households were more likely to have mixed fuels as their main fuel, especially in 2009, which may indicate a gradual shift to mixed fuels, i.e., using both modern energy sources and solid fuels, for cooking over time. This suggests a tendency towards fuel stacking over time.

Conclusions

Due to the environmental and health effects of using traditional fuels for cooking, the government of Ethiopia has been trying to reverse the trend by following different approaches, such as the promotion of improved biomass cook stoves and inter-fuel substitution in favor of

modern fuels. This concern is mainly because a shift to modern energy sources will reduce pressure on forests and the use of traditional fuels has local environmental impacts such as smoke, smog and indoor air pollution. In general, use of modern energy services will improve the health and socio-economic welfare of households (OECD/IEA, 2010). Having the right strategy in the promotion of energy transition requires a good understanding of the driving factors that influence energy choice. In this regard available evidences that are based on rigorous studies are limited and hence further empirical evidence from developing countries will help in the design of strategies for intervention by governmental and non-governmental organizations working in the area of energy and environment.

In this study we identify and understand various socioeconomic factors that determine household fuel choice in urban Ethiopia. We use three rounds of the Ethiopian Urban Socio-economic Survey - a panel data collected in 2000, 2004, and 2009 from households in different parts of the country. This is the main contribution of this study as most related studies are based on cross section data which do not allow us to control for unobserved heterogeneity and analysis of changes over time. We do the analysis by categorizing energy sources into solid, mixed and clean fuels.

Several factors affect the choice of a category of energy source by urban households in Ethiopia. The results show that household expenditure, price and education play an important role in determining fuel choice. The results suggest that increasing per capita income will promote clean fuel use (kerosene and electricity) and reduce consumption of solid fuels such as firewood, dung and crop residues. This suggests that economic growth can help facilitate fuel switching in urban areas of Ethiopia. However, income is not the only factor in the fuel switching process. We also find that prices play an important role in inter-fuel substitution. Thus, prices of energy sources such as firewood, kerosene and electricity can be used as important policy instruments to influence energy consumption behavior of urban households in Ethiopia. We also find evidence of fuel stacking, as there is an increase in the number of fuel types used by households as incomes rise. A tendency to shift from traditional fuels to mixed fuels is also observed over time.

But other measures should also be considered in the government's effort to achieve its objective of reducing the environmental and health damage associated with use of traditional fuel sources. Our results suggest that education is a key variable that can be used to promote fuel switching as higher education levels are associated with a higher probability of clean fuel use and a lower incidence of solid fuel use. We also find that modern fuels are chosen in relatively big cities in the country. Hence, as argued by Heltberg (2005), education and big city life play a

significant role in speeding up cultural change and facilitating the transition from traditional fuels to adoption and consumption of modern fuels, including new cooking techniques.

Future research in this area may focus on understanding the extent to which the demand for electricity, LPG, kerosene, and wood fuels is sensitive to income and price change by using longitudinal data. Such studies could help in the design of better strategies and policy instruments in the energy sector.

References

Alem, Y., and M. Soderbom. 2012. "Household Level Consumption in Urban Ethiopia: The Effects of a Large Food Price Shock." *World Development* 40: 146-162.

Bacon, R., S. Bhattacharya, and M. Kojima. 2010. "Expenditure of Low-Income Households on Energy: Evidence from Africa and Asia." Extractive Industries for Development Series #16. Washington, DC: World Bank.www.worldbank.org/ogmc (or /oil or /gas or /mining).

Barnes, D.F., K. Krutilla, and W. Hyde. 2004. "The Urban Household Energy Transition, Energy, Poverty, and the Environment in the Developing World." Washington, DC. World Bank.

Beyene, A.D., and S.F. Koch. 2012. "Clean Fuel Saving Technology Adoption in Urban Ethiopia." *Energy Economics* 36: 605-613.

Butler, J.S., and R. Moffitt. 1982. "A Computationally Efficient Quadrature Procedure for the One-factor Multinomial Probit Model." *Econometrica* 50: 761-764.

Chambwera, M., and H. Folmer. 2007. "Fuel Switching in Harare: An Almost Ideal Demand System Approach." *Energy Policy* 35: 2538–2548.

Dewees, P.A. 1989. "The Woodfuel Crisis Reconsidered: Observations on the Dynamics of Abundance and Scarcity." *World Development* 17: 1159–1172.

EIA (Energy Information Administration of the USA). 2010a. International Energy Outlook 2010. Washington, DC: EIA.

EIA (Energy Information Administration of the USA). 2010b. World Energy Projection System Plus: Residential Model. Washington, DC: EIA.

EIA (Energy Information Administration of the USA). 2011. International Energy Outlook 2011. Washington, DC: EIA.

Gebreegziabher, Z., A. Mekonnen, M. Kassie, and G. Kholin. 2012. "Urban Energy Transition and Technology Adoption: The Case of Tigrai, Northern Ethiopia." *Energy Economics* 34: 410–418.

Glick, P., and D. Sahn. 2005. "Intertemporal Female Labor Force Behavior in a Developing Country: What Can We Learn from a Limited Panel?" *Labor Economics* 12: 23-45.

Greene, W.H. 2003. *Econometric Analysis*. 5th ed. Prentice Hall-Pearson Education International.

Gupta, G., and G. Köhlin. 2006. "Preferences in Urban Domestic Fuel Demand: The Case of Kolkata, India." *Ecological Economics* 57(1): 107-121.

Haan, P., and A. Uhlendorff. 2006. "Estimation of Multinomial Logit Models with Unobserved Heterogeneity Using Maximum Simulated Likelihood." *The Stata Journal* 6: 229-245.

Heltberg, R. 2005. "Factors Determining Household Fuel Choice in Guatemala." *Environment and Development Economics* 10: 337-361.

Heltberg, R. 2004. "Fuel Switching: Evidence from Eight Developing Countries. *Energy Economics* 26: 869-887.

IEA (International Energy Agency). 2002. World Energy Outlook. Paris: OECD.

IEA (International Energy Agency). 2005. World Energy Outlook. Paris: OECD.

Jiang, L., and B.C. O'Neill. 2004. "The Energy Transition in China." *International Journal of Global Energy Issues* 21(1/2): 2-26.

Kebede, B., A. Bekele, and E. Kedir. 2002. "Can the Urban Poor Afford Modern Energy? The Case of Ethiopia." *Energy Policy* 30: 1029-1045.

Leach, G. 1992. "The Energy Transition." *Energy Policy* 20(2): 116-123.

Lewis, J.J., and S.K. Pattanayak. 2012. "Who Adopts Improved Fuels and Cookstoves? A Systematic Review." *Environmental Health Perspectives* 120(5): 637-645.

Masera, O., B. Saatkamp, and D. Kammen. 2000. "From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model." *World Development* 28(12): 2083-2103.

Mekonnen, A., and G. Köhlin. 2008. "Determinants of Household Fuel Choice in Major Cities in Ethiopia." Environment for Development Discussion Paper Series, EfD DP 08-18.

MoWE (Ministry of Water and Energy). 2011. Energy Balance and Statistics for Years 2005/6-2009/10. Addis Ababa, Ethiopia.

Narasimha, M.R., and B.S. Reddy. 2007. "Variations in Energy Use by Indian households: An Analysis of Micro Level Data." *Energy* 32: 143-153.

Ouedraogo, B. 2006. "Household Energy Preferences for Cooking in Urban Ouagadougou, Burkina Faso." *Energy Policy* 34: 3787-3795.

OECD/IEA. 2010. "Energy Poverty: How to Make Modern Energy Access Universal?" Special
early excerpt of the World Energy Outlook 2010 for the UN General Assembly on the
Millennium Development Goals. Retrieved from:
http://www.worldenergyoutlook.org/media/weowebsite/2010/weo2010_poverty.pdf

OECD/IEA.2006. "Energy for cooking in developing countries," Retrieved from:
http*://*www.worldenergyoutlook.org/media/weowebsite/2008.../WEO2006.pdf

Rabe-Hesketh, S., and A. Skrondal. 2005. "Multilevel and Longitudinal Modeling Using Stata."
College Station, TX: Stata Press.

UNDP (United Nations Development Programme). 2005. "Achieving the Millennium
Development Goals: The Role of Energy Services." Case studies from Brazil, Mali and
the Philippines.

UNDP/WHO (United Nations Development Programme/World Health Organization). 2009.
"The Energy Access Situation in Developing Countries: A Review Focusing on Least
Developed Countries and Sub-Saharan Africa." http://www.undp.org/energy.

Wolfram, C., O. Shelef, and P. Gertler. 2012. "How Will Energy Demand Develop in the
Developing World?" *Journal of Economic Perspectives* 26(1): 119-138.

World Growth. 2009. "Forestry and the Poor: How Forestry Reduces Poverty." A World Growth
Report.

Tables and Figures

Table 1. Definition and descriptive statistics of variables 2000-2009 (N= 2917)

Variable Definition	Mean	SD
Dependent variables		
Main cooking energy is clean (%)	0.464	-
Main cooking energy is mixed fuels (%)	0.272	-
Main cooking energy is solid energy (%)	0.264	-
Explanatory variables		
Price of firewood per kg	0.844	0.657
Price of charcoal per kg	1.136	0.602
Price of kerosene per liter	2.373	0.931
Price of electricity per kwh	0.324	0.109
Monthly real consumption per adult equv	155.49	183.96
Household size	5.687	2.656
Age of head	51.13	13.95
Head male	0.541	0.498
Proportion of females in household	0.329	0.221
Number of children	1.485	1.429
Head illiterate*	0.255	0.436
Head primary schooling	0.295	0.456
Head junior secondary schooling	0.146	0.353
Head secondary schooling	0.222	0.416
Head tertiary schooling	0.083	0.276
Resides in Addis	0.716	0.451
Resides in Awassa	0.091	0.287
Resides in Dessie	0.098	0.297
Resides in Mekelle	0.096	0.295
Dummy for year 2000	0.375	0.484
Dummy for year 2004	0.382	0.486
Dummy for year 2009	0.243	0.429

Table 2. Random-effects multinomial logit estimates of household fuel choice

Variable	Mean	SD
Mixed Fuel		
Firewood log price	-0.198**	0.088
Charcoal log price	-0.226	0.140
Kerosene log price	0.037	0.177
Electricity log price	0.966***	0.331
Log real consumption per AEU	-0.351***	0.086
Log household size	0.120	0.149
Age of head	-0.002	0.005
Head, Male	0.053	0.130
Share of females in household	-0.603*	0.310
Number of children	0.023	0.056
Head primary schooling completed	-0.278*	0.156
Head junior secondary schooling completed	-0.445**	0.191
Head secondary schooling completed	-0.614***	0.178
Head tertiary schooling completed	-0.876***	0.241
Addis	-1.966***	0.255
Awassa	0.427	0.332
Dessie	1.159***	0.364
2004	0.305**	0.138
2009	0.996***	0.351
Intercept	3.838***	0.706
Solid Fuel		
Firewood log price	-0.569***	0.104
Charcoal log price	0.067	0.161
Kerosene log price	1.775***	0.192
Electricity log price	0.592	0.394
Log real consumption per AEU	-0.949***	0.107
Log household size	-0.616***	0.172
Age of head	0.006	0.005
Head, Male	-0.016	0.156
Share of females in household	0.148	0.361
Number of children	0.142**	0.066
Head primary schooling completed	-0.496***	0.177
Head junior secondary schooling completed	-0.600***	0.222
Head secondary schooling completed	-0.911***	0.212
Head tertiary schooling completed	-1.764***	0.326
Addis	-2.212***	0.282
Awassa	1.061***	0.358
Dessie	1.022***	0.390
2004	-0.018	0.160
2009	0.332	0.417
Intercept	5.208***	0.835
Heterogeneity Covariances		
Var(a1)	0.726***	0.227
Var(a2)	1.432***	0.244
Cov(a1, a2)	1.197***	0.155
Log-likelihood	-2468.615	
N	2917	

Note: ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

Note: Clean fuel type is base category.

Table 3. Marginal effects of household fuel choice (computed from Table 2)

Variable	Clean	Mixed	Solid
Firewood log price	0.083***	0.001	-0.084**
Charcoal log price	0.022	-0.053**	0.031
Kerosene log price	-0.159***	-0.138***	0.296***
Electricity log price	-0.163***	0.160***	0.004
Log real consumption per AEU	0.129***	0.002	-0.130***
Log household size	0.031	0.079***	-0.110***
Age of head	0.000	-0.001	0.001
Head, Male	-0.010	0.013	-0.003
Share of females in household	0.068	-0.139**	0.071
Number of children	-0.014	-0.007	0.021***
Head primary schooling completed	0.082***	-0.022	-0.060***
Junior secondary schooling completed	0.120***	-0.052*	-0.068***
Head secondary schooling completed	0.176***	-0.072***	-0.104***
Head tertiary schooling completed	0.265***	-0.093***	-0.172***
Addis	0.367***	-0.199***	-0.168***
Awassa	-0.151***	-0.016	0.167***
Dessie	-0.223***	0.160***	0.063
2004	-0.037	0.065**	-0.028
2009	-0.139**	0.188***	-0.050

Note: ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

**Figure 1. Proportion of sample households using clean, solid and mixed energy as main
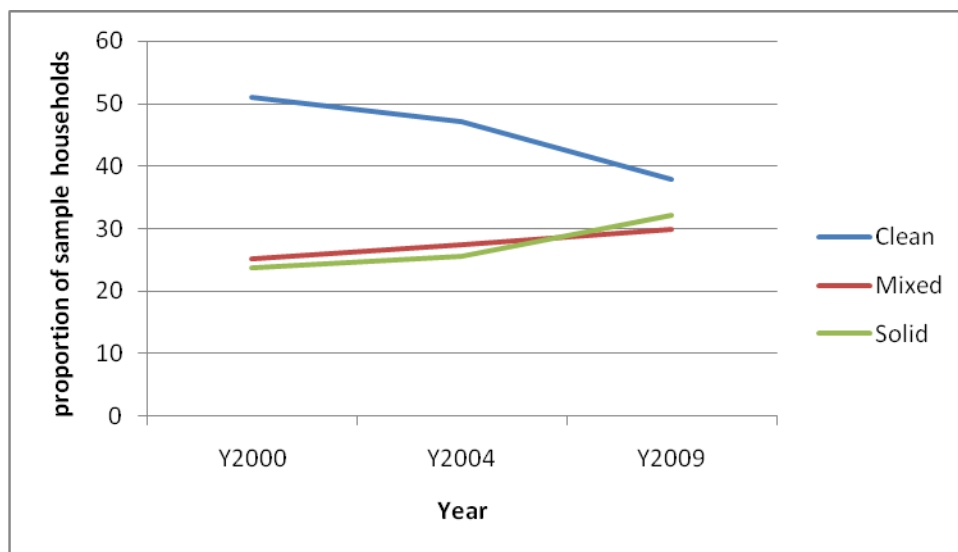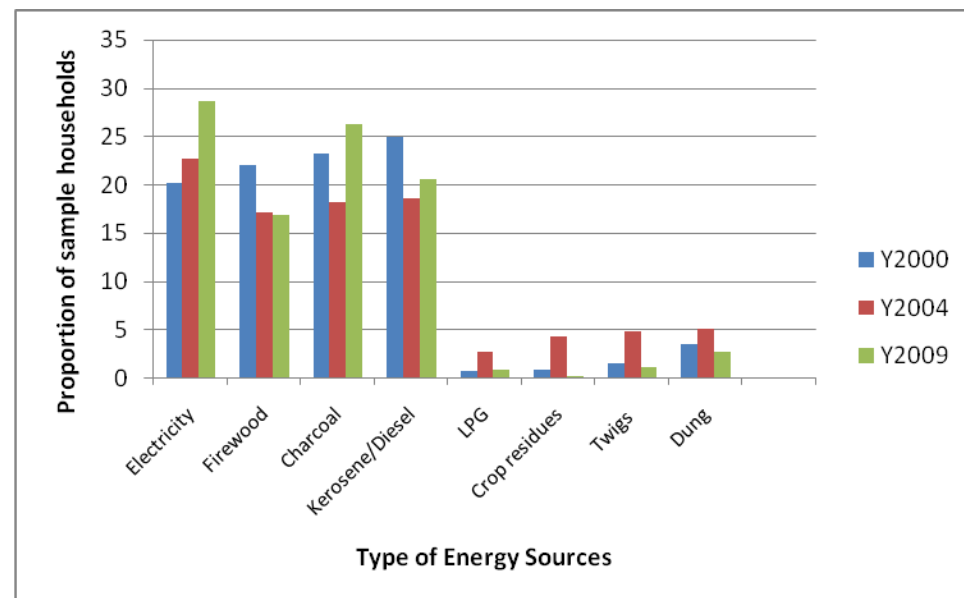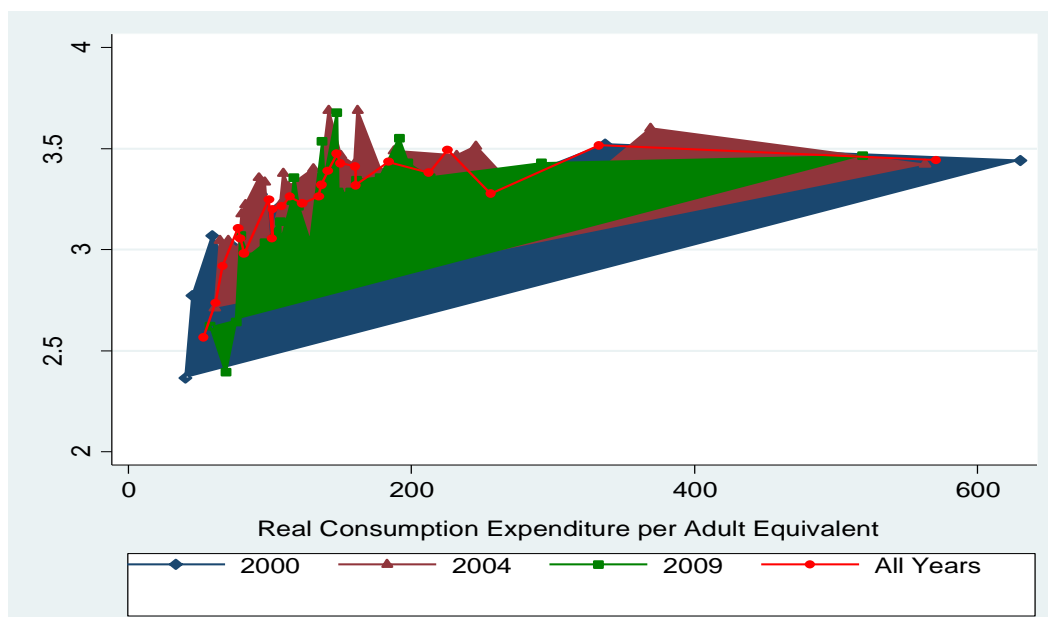energy sources by survey year**

Figure 2. Proportion of sample households using energy sources by survey year

Figure 3. Average number of energy types households used by per adult equivalent monthly expenditure

Appendices

Appendix A: Descriptive statistics by year

	Year 2000		Year 2004		Year 2009	
Variable	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Price of firewood per kg	0.89	0.61	1.09	0.73	0.38	0.23
Price of charcoal per kg	1.12	0.50	1.45	0.63	0.67	0.32
Price of kerosene per liter	2.15	0.99	2.50	0.84	2.52	0.91
Price of electricity per kwh	0.38	0.06	0.38	0.05	0.15	0.03
Monthly real consumption per adult equiv	153.33	225.39	160.32	164.69	151.22	135.19
Household size	6.04	2.75	5.71	2.69	5.10	2.34
Age of head	49.77	13.42	50.53	14.11	54.18	14.06
Head male	0.57	0.50	0.54	0.50	0.50	0.50
Share of females in household	0.32	0.22	0.33	0.22	0.35	0.23
Number of children	1.77	1.59	1.47	1.38	1.08	1.11
Head illiterate*	0.17	0.37	0.31	0.46	0.30	0.46
Head primary schooling	0.32	0.46	0.27	0.44	0.30	0.46
Head junior secondary schooling	0.13	0.33	0.15	0.36	0.17	0.37
Head secondary schooling	0.34	0.47	0.17	0.38	0.11	0.31
Head tertiary schooling	0.05	0.21	0.10	0.29	0.12	0.33
Resides in Addis	0.77	0.42	0.74	0.44	0.59	0.49
Resides in Awassa	0.07	0.25	0.09	0.28	0.14	0.34
Resides in Dessie	0.08	0.28	0.09	0.28	0.14	0.34
Resides in Mekelle	0.08	0.28	0.08	0.28	0.14	0.34
Number of Observations (N)	1093		1115			709

Appendix B: Household model of fuel choice: Pooled multinomial logit estimates

Variable	Mean	SD
Mixed Fuel		
Firewood log price	-0.184**	0.080
Charcoal log price	-0.210*	0.125
Kerosene log price	-0.052	0.160
Electricity log price	0.851***	0.299
Log real consumption per AEU	-0.288***	0.076
Log household size	0.167	0.132
Age of head	-0.003	0.004
Head, Male	0.063	0.113
Share of females in household	-0.573**	0.274
Number of children	0.012	0.049
Head primary schooling completed	-0.249*	0.138
Head junior secondary schooling completed	-0.415**	0.170
Head secondary schooling completed	-0.596***	0.160
Head tertiary schooling completed	-0.814***	0.215
Addis	-1.633***	0.213
Awassa	0.357	0.290
Dessie	1.066***	0.323
2004	0.275**	0.127
2009	0.848***	0.318
Intercept	3.166***	0.613
Solid Fuel		
Firewood log price	-0.557***	0.091
Charcoal log price	0.085	0.140
Kerosene log price	1.663***	0.162
Electricity log price	0.387	0.343
Log real consumption per AEU	-0.864***	0.090
Log household size	-0.552***	0.144
Age of head	0.004	0.004
Head, Male	0.013	0.130
Share of females in household	0.157	0.304
Number of children	0.127**	0.056
Head primary schooling completed	-0.462***	0.151
Head junior secondary schooling completed	-0.584***	0.190
Head secondary schooling completed	-0.892***	0.182
Head tertiary schooling completed	-1.679***	0.288
Addis	-1.745***	0.217
Awassa	0.981***	0.293
Dessie	0.907***	0.328
2004	-0.042	0.143
2009	0.113	0.365
Intercept	4.374***	0.698
Log-likelihood	-2486.449	
N	2917	

Note: ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

Note: Clean fuel type is base category.