UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

WORKING PAPERS IN ECONOMICS

No 632

Modelling Household Cooking Fuel Choice: a Panel Multinomial Logit Approach

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

October 2015

ISSN 1403-2473 (print)
ISSN 1403-2465 (online)

Department of Economics
School of Business, Economics and Law at University of Gothenburg
Vasagatan 1, PO Box 640, SE 405 30 Göteborg, Sweden
+46 31 786 0000, +46 31 786 1326 (fax)
www.handels.gu.se info@handels.gu.se

EFMD EQUIS ACCREDITED

Modelling Household Cooking Fuel Choice: a Panel Multinomial Logit Approach*

Yonas Alem† Abebe D. Beyene‡ Gunnar Köhlin § Alemu Mekonnen¶

August 25, 2015

Abstract

We use three rounds of a rich panel data set to investigate the determinants of household cooking fuel choice and energy transition in urban Ethiopia. We observe that the expected energy transition did not occur following economic growth in Ethiopia during the decade 2000-2009. Regression results from a random effects multinomial logit model suggest 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" by households. We argue that policy makers could target these policy levers to encourage transition to cleaner energy sources.

JEL Classification: C25, Q23, Q42, O13.

Keywords: Ethiopia, urban, energy choice, random effects multinomial logit.

*The authors would like to thank two anonymous referees for helpful comments. Financial support from Sida through the Environment for Development initiative (EfD) of the Environmental Economics Unit, Department of Economics, and the Gothenburg Center of Globalization, University of Gothenburg is gratefully acknowledged. All errors and omissions are of the authors.

†Department of Economics, University of Gothenburg, Sweden; e-mail: yonas.alem@economics.gu.se.

‡Environmental Economics Policy Forum, EDRI, Ethiopia, e-mail: abebed2002@yahoo.co.uk

§Department of Economics, University of Gothenburg, Sweden, e-mail: gunnar.kohlin@economics.gu.se

¶Department of Economics, Addis Ababa University, Ethiopia, e-mail: alemu_m2004@yahoo.com

1. Introduction

While 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 as fuel (IEA, 2004), this has not happened in many African cities (Chambwera and Folmer, 2007). Although Ethiopia, which is the focus of this study, is endowed with a variety of clean energy sources, such as hydropower, geothermal, wind, and solar, 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). 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).

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 help in reducing poverty, improving health of citizens, promoting gender equality and enhancing sustainable management of natural resources.

However, households in most developing countries are highly dependent on traditional fuels 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 even more serious in rural parts of Africa, still only 42%

of the urban people in sub-Saharan Africa 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 health and environmental problems in 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 fuelwood (firewood) consumption for cooking. Africa has the highest per capita fuelwood consumption in the world (0.89 m^3/year) and without major changes which are unlikely to happen the associated deforestation and forest degradation is likely to continue in the foreseeable future (Chambwera and Folmer, 2007). Extreme poverty and lack of access to other fuel sources contribute to the heavy dependence of the population of sub-Saharan Africa on traditional fuels (IEA, 2002).

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 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, studies suggest that access to electric light provides extra hours for reading by extending the day and hence helps improve the school performance of children (OECD, 2007). 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, due to reduction in daily exposure to noxious cooking fumes.

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 though growing. Existing studies on adoption of clean energy sources by households in developing countries remain scattered and largely qualitative; and 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) as opposed to the previously expected smooth transition to modern fuels with increased income and urbanization. This has not been carefully examined, especially in Africa (Masera et al., 2000). Mekonnen and Köhlin (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. Therefore, a better understanding of the factors that hinder the transition to modern fuels using more rigorous methods will help to design interventions by both governmental and nongovernmental organizations working on energy and energy related issues.

The questions this study attempts to answer include: what are the socioeconomic factors that determine households' cooking fuel choice in urban Ethiopia? How does the pattern of cooking energy consumption in urban households change over time and across income groups? 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 rapid economic growth but also high inflation. According to the World Bank report, the inflation rate during our study period (2000-2009) ranged from -8 to 44 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 biomass, 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 countries, such as Ethiopia.

---

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

Regression results from a random effects multinomial logit model that controls for unobserved household heterogeneity suggest that the price of alternative fuel types, economic status and education are important determinants of household cooking fuel choice. An increase in the price of firewood reduces the demand for biomass and mixed fuels but it increases the demand for clean fuels. An increase in the price of kerosene on the other hand reduces its demand while it increases the demand for biomass fuel. These findings highlight the significant role that prices of alternative fuel play in household fuel switching. Results also highlight the key roles of important variables such as economic status and education of household members in promoting transition to modern fuel types.

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 related empirical studies. The third section presents the methods including data collection and the empirical model. Section four presents results and discussion. The last section presents conclusions and policy implications.

2. Fuel Switching and Choice in Developing Countries

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 fuel switching behavior of households. As noted by van der Kroon et al. (2013), 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). Modern fuels are often used alongside traditional biomass fuels, particularly in rural areas but also by large proportion of urban residents. A study by Ngui et al. (2011) in Kenya reveals multiple fuel use by households in their study. 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 Köhlin, 2008). Thus, studies suggest that economic factors are not the only determinants of household's fuel choice; several socio-demographic factors such as education and gender of the household heads are also important factors (Farsi et al., 2007). Other studies suggest that tastes and cultural preferences are also factors influencing choice of fuel sources in several developing countries (Arthur et al., 2012; Farsi et al., 2007; Schlag and Zuzarte, 2008). 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).

[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.

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/supply (OECD/IEA, 2006). Another reason could be household 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 while fulfilling the needs of consumers.

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. For example, as household size increases, the household switches to other fuel types such as charcoal, fuelwood and LPG to meet increased demand for energy (Ngui et al., 2011). A large household size with many females translates into low opportunity costs of to collect firewood, and therefore often leads to fuel stacking. Similar conclusions were reached by other studies such as van der Kroon, et al. (2013) and Narasimha and Reddy (2007). Heltberg (2004) analyzed the determinants of fuel switching using comparable household survey 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 switching. He argued that larger households are more likely to consume multiple fuels, both biomass and non-biomass. Education is also another important household characteristic that has been included in studies on energy demand. Studies by Narasimha and Reddy (2007) in India, Mekonnen and Köhlin (2008) in urban Ethiopia, Farsi et al.(2007), Njong and Johannes (2011) 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 Farsi et al. (2007) better education helps households to be aware of the negative effects of using biomass fuels such as firewood, and increases the awareness with regard to the advantages of modern fuel use, in terms of efficiency and convenience. Chambwera and Folmer (2007) note that education can be considered as a long-term policy to handle and manage the demand for firewood.

Gupta and Köhlin (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). Ekholm et al. (2010) argue that subsidy could increase labor productivity in the long term, as the time used for gathering and using firewood could be used more profitably in other productive activities and gradually help households shift to cleaner fuels. 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 Köhlin (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 fuelwood, 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.

3. Methods

3.1. Data Collection and Sampling

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 administrative units.

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

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 Söderbom (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.

It is reasonable to be concerned about bias in the estimation results as a result of attrition given that the sample size had to be reduced substantially in the most recent wave. Alem (2015) and Alem et al. (2014), previous authors who used the panel dataset for related research, attempted to investigate attrition bias using attrition probits (Fitzgerald et al., 1998) and a Becketti, Gould, Lillard, and Welch (BGLW) test (Becketti et al., 1988). Attrition probits represent estimates of binary-choice models for the determinants of attrition in later periods as a function of base year characteristics. The BGLW test, on the other hand, involves investigating

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

the effect of future attrition on the initial period's outcome variable. Based on these tests, the authors conclude that it is unlikely that attrition in the sample would bias the results for the remaining sample.

The panel data set contains information on household energy choice and 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 unbalanced panel of all households surveyed in the three waves in all the four cities comprising 2917 observations. Table 1 shows the number of households covered in the three surveys disaggregated by urban areas.

Table 1 about here

The dependent variables we focus on this paper are energy types chosen by households as their main cooking fuel. Clean energy users are those households who use electricity, gas and kerosene as their main energy source for cooking.[5],[6] The other categories used in this study are mixed and biomass fuels. The category 'biomass fuel', as the name implies, refers to energy sources such as firewood, charcoal, dung and crop residues. The term 'mixed fuels' refers to a combination of clean and biomass fuels. These are households that use a combination of clean

---

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

6 The main variable of interest - household cooking fuel used - has been constructed from the response to the survey question "what is your main source of energy for cooking?".

energy types such as electricity and gas for one type of cooking activity and biomass fuel such as firewood and/or charcoal for other types of cooking according to their response.

We investigate the determinants of cooking energy choice in urban Ethiopia under three headings: economic variables, household characteristics, and city and time dummies. The economic variables include the price of firewood, charcoal, electricity and real per capita consumption expenditure. We computed aggregate household consumption expenditure by adding up reported household expenditure on food and non-food items. The non-food component of consumption includes expenditures on items such as clothing, footwear, energy, personal care, utilities, health and education. To correct for spatial and temporal price differences, we divided nominal consumption expenditure by carefully constructed price indices from the survey, and computed real consumption expenditure. We then divided real household level consumption expenditure by adult equivalent units to adjust for difference in needs and economies of scale in consumption.

The household characteristics constitute conventional variables used in previous adoption literature: age, education, and gender of the household head, and other household-level variables including household size, the share of females in the household, and number of children. Definition of all the explanatory variables used in the analysis is presented in appendix A.

3.2. Empirical Model

We estimate a panel multinomial logit model to investigate the effect of price of alternative energy sources and other relevant household-level variables on cooking energy choice in urban Ethiopia. The theoretical framework of the multinomial logit model has each household

i faced with J different cooking choices at time t. The household receives a certain level of utility from each cooking energy choice and chooses the alternative that maximizes its utility. We assume that each household chooses between three cooking energy states at each time t: clean fuel only (j = 1), a mix of clean and biomass fuels (j = 2), and biomass fuel only (j = 3).

Estimation of the standard multinomial logit model using the pooled sample (ignoring individual heterogeneity) would be the starting option to consider to model cooking energy choice by households in urban Ethiopia. However, this model assumes that households' choices are independent, both within a choice (that is, for multiple observations across time of the same choice) and across all alternative choices made by the household over time. The random effects specification relaxes the assumption that multiple observations within a choice are independent. With this model, the choice probabilities for repeated choices made by household i share the same time-invariant unobserved heterogeneity α_{ij}, where the household-specific effects act as a random variable that produces a correlation among the residuals for the same household within choices, but leaves the residuals independent across households.

The utility of a cooking energy state j in time period t in a random effects context can therefore be specified as:

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

where X'_{it} is a vector of explanatory variables such as the price of alternative energy types, income and other socio-economic variables that are expected to affect fuel choice, α_{ij} is a time-invariant unobserved household heterogeneity, and ε_{ijt} are random error terms that are independently and identically distributed. The vector β_j represents the coefficients 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 α_i, 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:

$$L=\prod_{i=1}^{N}\int_{-\infty}^{\infty}\prod_{t=1}^{T}\prod_{J=1}^{J}\left\{\frac{exp\left(X_{it}^{/}\beta_{j}+\alpha_{ij}\right)}{\sum_{s=0}^{2}exp\left(X_{it}^{/}\beta_{s}+\alpha_{is}\right)}\right\}^{d_{ijt}}f(\alpha)d\alpha \quad (3)$$

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, α is 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."

4.Results and Discussion

4.1. Descriptive Statistics

Table 2 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. The proportion of sample households who depend on mixed (biomass and non-biomass) energy and biomass energy as main energy sources is 27.2% 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. Descriptive statistics of variables over time are presented in table A2 in the appendix.

Table 2 about here

Figure 1 shows the proportion of sample households using clean, mixed and biomass 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 biomass fuels as their main cooking energy over the three survey years. The t-test that compares the means between the two groups (the null hypothesis being that the difference between the means of clean and biomass; clean and mixed, and biomass and mixed is zero), shows that the difference between means of clean fuels and other categories of fuels (i.e. biomass and mixed) is statistically significantly different from zero. But the difference between mixed fuels and biomass fuels is not significantly different from zero.

Figure 1 about here

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.

Figure 2 about here

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 kerosene as main energy source 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) as their main source of fuel has decreased over time. On the other hand, Figure 2 shows that the proportion of households who used electricity (have access to 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.[7]

Figure 3 about here

[7] 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.

Figure 3 shows the average number of different fuels that households used by per adult equivalent real monthly expenditure.[8] 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 is an indicator 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'[9] behavior.[10] As argued by Mekonnen and

---

[8] 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.

[9] A weakness of using the number of fuels used by households as an indicator of 'fuel stacking' behavior is that it is more general than an alternative definition that considers the share of a fuel type in total energy consumed. For example, with such an alternative definition, there could be two households that use both biomass and modern fuels. If the share of modern fuels consumed by one of these is very high (and this household is rich) and that of the other is very small (and this is poor), it could support the energy ladder hypothesis. We do not have the appropriate data to test this. However, considering the number of fuels is still important as it helps us compare the extremes (ie, those who use a fuel type versus those who do not). We thank an anonymous reviewer for pointing this out.

[10] A test of the pair wise comparisons of means (adjusted for multiple comparisons using Duncan's method) of the average number of fuels used shows that the average number of fuels used by households is not statistically

Köhlin (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 (2013) 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. The use of multiple fuels or 'fuel stacking' can also be because of culture and tradition. For example, there is a tendency for choosing some fuel types and stoves for cooking some meals.

The pattern of energy use by city shows that clean, mixed, and biomass 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 households in Addis Ababa depended on clean fuels for cooking in the year 2000. This proportion increased to about 56% in 2009.[11] The t-test that compares the means between the two groups in Addis (the null hypothesis being that the difference between the means of clean and biomass; clean and

---

significant for groups of higher expenditure categories. But most of the comparisons between higher and lower expenditure categories show that the mean values are different and statistically significant. The test result was not reported in order to save space but are available from the authors upon request.

[11] But those who used only clean fuels for cooking were around 62% in 2000, which declined to 60.3% in 2004 and further declined to 57.24% in 2009. This shows that households have relied less on clean fuels only for cooking perhaps due to the frequent interruption of power in cities; a problem that has been occurring quite frequently over the last decade. But the proportion of households who used only mixed fuels for cooking increased from 20.5% in 2000 to 23.6% in 2004 and 28.3% in 2009, which supports the above argument.

mixed, and biomass and mixed is zero), shows that they are all statistically different from zero. 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 biomass for cooking in Addis from 17.5 % in 2000 to 14.5% in 2009. In particular firewood for cooking in Addis declines overtime (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.

4.2. Empirical Results

Regression results for determinants of household energy choice in urban Ethiopia are presented in Tables 3 and 4. The regression results from a pooled multinomial logit model which does not control for unobserved household heterogeneity are presented in table A3 in the appendix. While Table 3 shows the estimated coefficients, Table 4 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.

Table 3 about here

As we can see from the estimation results in Tables 3 and 4, 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 biomass and mixed fuels decreases. In other words, households tend to shift to clean fuel sources, such as electricity and relatively cleaner sources (compared to biomass fuel types) such as kerosene, when firewood price increases. More specifically, 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 biomass fuels by 0.84 percent. That means that policies that lead to real increases in the price of firewood, e.g. by reducing its availability, may be a viable strategy to promote fuel switching by urban households. Introducing REDD+ (Reducing Emissions from Deforestation and Forest Degradation) could be mentioned as an example, which may have the effect of reducing availability of fuelwood and possibly also increasing the price of firewood.

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 biomass fuels. This suggests that households do not switch back to biomass fuels as price of electricity increases.

An increase in kerosene price has a positive and significant effect on the choice of biomass 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 biomass fuels by 3 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 a policy instrument to consider in order to reduce the consumption of biomass fuels such as firewood and charcoal and increase the use of other energy sources such as kerosene. However, as argued by Kebede et al. (2002), the targeting of a kerosene subsidy to the poor is problematic, and non-poor households are likely to capture most of the subsidies if it were to be done 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 changing the fuel price can actually 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 biomass 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;Farsi et al, 2007). The literature also suggests that households tend to switch to a multiple fuel-use strategy (fuel stacking) as their incomes rise for a number of reasons including reliability of supply and convenience of use of stoves and fuel types. 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 strategies.

Table 4 about here

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 biomass fuels such as firewood and charcoal. The plausible explanation for this is that education enables individuals to understand the negative effects of using biomass fuels both on health (Mekonnen and Köhlin, 2008) and possibly on the environment. 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 biomassfuels, 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 biomas sand non-biomass (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 biomass 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 biomass 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 biomass fuels, for cooking over time. This suggests a tendency towards fuel stacking over time.

5. Conclusions and Policy Implications

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 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 controlling for unobserved heterogeneity and analysis of changes over time. We do the analysis by categorizing energy sources into biomass, 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 conform with previous studies in so far as increasing per capita income will promote clean fuel use (kerosene and electricity) and reduce consumption of biomass fuels such as firewood, dung and crop residues. Economic growth will therefore help facilitate fuel switching in urban areas of Ethiopia, in line with the fuel ladder hypothesis. 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 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 biomass fuel use. Given the other benefits that accrue from education, and the inherent problems with fuel subsidies and taxation, increased education levels appear as an interesting strategy. 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 Soderbom, M., 2012. Household Level Consumption in Urban Ethiopia: The Effects of a Large Food Price Shock. World Development 40: 146-162.

Alem, Y. (2015). Poverty dynamics and intra-household heterogeneity in occupations: Evidence from urban Ethiopia, Oxford Development Studies, 43(1), 20-43.

Alem, Y., K¨ohlin, G., & Stage, J. (2014). The Persistence of Subjective Poverty in Urban Ethiopia. World Development, 56, 51-61.

An,L., Lupi,F., Liu,J., Linderman,M.A., Huang,J.2002. Modeling the choice to switch from fuelwood to electricity Implications for giant panda habitat conservation. Ecological Economics 42: 445-457.

Arthur, M., C.A. Bond, and Willson, B., 2012. Estimation of Elasticities for Domestic Energy Demand in Mozambique. Energy Economics34(2):398-409.

Bacon, R., S. Bhattacharya, and Kojima, M., 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,W., 2004. The Urban Household Energy Transition, Energy, Poverty, and the Environment in the Developing World. Washington, DC. World Bank.

Beyene, A.D., and Koch, S.F., 2013. Clean Fuel Saving Technology Adoption in Urban Ethiopia. Energy Economics36: 605-613.

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

Chambwera, M., and Folmer, H., 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 Development17: 1159–1172.

Ekholm T, Krey V, Pachauri S & Riahi K., 2010. Determinants of household energy consumption in India. Energy Policy, 38(10):5696-5707.

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 Kholin,G., 2012. Urban Energy Transition and Technology Adoption: The Case of Tigrai, Northern Ethiopia. Energy Economics 34: 410–418.

Glick, P., and Sahn,D., 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 Köhlin,G., 2006. Preferences in Urban Domestic Fuel Demand: The Case of Kolkata, India. Ecological Economics 57(1): 107-121.

Haan, P., and Uhlendorff, A., 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 O'Neill,B.C., 2004. The Energy Transition in China. International Journal of Global Energy Issues 21(1/2): 2-26.

Kebede, B., Bekele, A., and Kedir, E., 2002. Can the Urban Poor Afford Modern Energy? The Case of Ethiopia. Energy Policy30: 1029-1045.

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

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

Masera, O., Saatkamp, B., and Kammen, D., 2000. From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model. World Development28(12): 2083-2103.

Farsi,M., Filippini,M., Pachauri,S., 2007. Fuel choices in urban Indian households.Environment and Development Economics12: 757–774.

Mekonnen, A., and Köhlin, G., 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 Reddy, B. S., 2007. Variations in Energy Use by Indian households: An Analysis of Micro Level Data. Energy 32:143-153.

Ngui, D., Mutua, J., Osiolo,H., Aligula, E., 2011. Household energydemandinKenya:An application of the linear approximate almost ideal demand system(LA-AIDS). Energy Policy 39: 7084–7094.

Njong,A.M., and Johannes,T.A., 2011. An analysis of domestic cooking energy choices in Cameroon.European Journal of Social Sciences*,* 20(2).

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

OECD/IEA,2007. OECD contribution to the United Nations commission on sustainable development (UNCSD-15) -Retrieved from *www.oecd.org/greengrowth/38509686.pdf*.

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 developingcountries,Retrieved from: http://www.worldenergyoutlook.org/media/weowebsite/2008.../WEO2006.pdf

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

Schlag,N., and Zuzarte,F.,2008.Market Barriers to Clean Cooking Fuels in Sub-Saharan Africa: A Review of Literature

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.

van der Kroon,B.,Brouwer,R., van Beukering, P,J., 2013.The energyladder:Theoreticalmythorempiricaltruth?Resultsfrom a meta-analysis. Renewable and Sustainable Energy Reviews 20: 504–513.

Wolfram, C., Shelef,)., and Gertler, P., 2012. How Will Energy Demand Develop in the Developing World? Journal of Economic Perspectives26(1): 119-138.

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

Table 1. Number of sample households by city over time

	Year			
City	2000	2004	2009	Total
Addis	839	828	421	2088
Awassa	72	96	96	264
Dessie	92	97	96	285
mekelle	90	94	96	280
Total	1093	1115	709	2917

Table 2. Descriptive statistics of variables (2000-2009)

Variable	Mean	SD
Economic variables		
Firewood log price	0,84	0,66
Charcoal log price	1,13	0,60
Kerosene log price	2,37	0,94
Electricity log price	0,32	0,11
Log real consumption per AEU	155,49	183,96
Household-level variables		
Age of head	51,13	13,95
Head, male	0,54	0,50
Head, female	0,46	0,50
Head illiterate	0,25	0,44
Head primary schooling completed	0,29	0,46
Head junior secondary schooling completed	0,15	0,35
Head secondary schooling completed	0,22	0,42
Head tertiary schooling completed	0,08	0,28
Household size	5,69	2,66
Share of females in household	0,33	0,22
Number of children	1,48	1,43
City dummies		
Addis	0,72	0,45
Awassa	0,09	0,29
Dessie	0,10	0,30
Mekelle	0,10	0,29
Observations	2917	

Table 3. Random-effects multinomial logit estimates of household fuel choice

-	Coeff.	SE
Mixed Fuel		
Economic variables		
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
Household-level variables		
Age of head	-0.002	0.005
Head, Male	0.053	0.130
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
Log household size	0.120	0.149
Share of females in household	-0.603*	0.310
Number of children	0.023	0.056
City and time dummies		
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
Biomass Fuel		
Economic variables		
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
Household-level variables		
Age of head	0.006	0.005
Head, Male	-0.016	0.156
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

Log household size	-0.616***	0.172
Share of females in household	0.148	0.361
Number of children	0.142**	0.066
City and time dummies		
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	-2468.61	
Observations	2917	

Notes: Clean fuel type is base category; ***p<0.01, **p<0.05, *p<0.1

Table 4. Marginal effects (computed from table 3)

	Clean	Mixed	Biomass
Economic variables			
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***
Household-level variables			
Age of head	0.000	-0.001	0.001
Head, Male	-0.010	0.013	-0.003
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***
Log household size	0.031	0.079***	-0.110***
Share of females in household	0.068	-0.139**	0.071
Number of children	-0.014	-0.007	0.021***
City and time dummies			
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

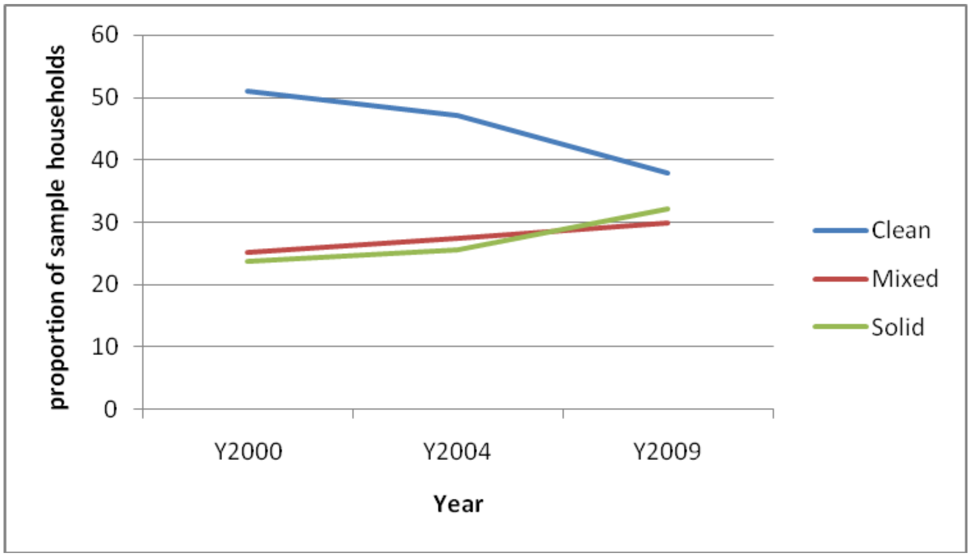

Figure 1: Proportion of sample households using clean, biomass and mixed energy as main energy sources by survey year

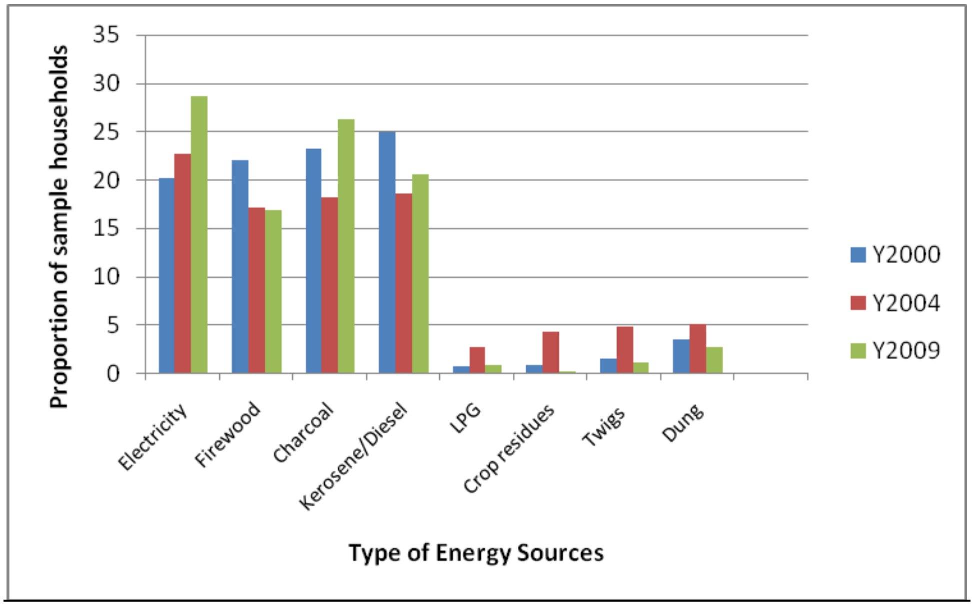

Figure 2. Proportion of sample households using energy sources by survey year

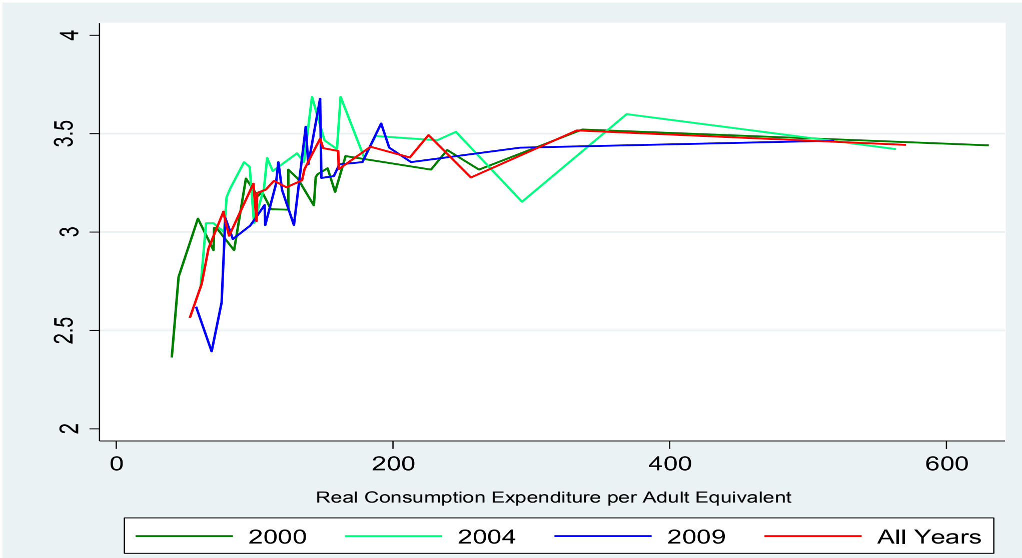

Figure 3. Average number of energy types households used by per adult equivalent monthly expenditure

Appendix

Table A1 here

Table A2. Descriptive statistics of variables over time

	2000		2004		2009	
	Mean	SD	Mean	SD	Mean	SD
Dependent variables						
Main cooking energy clean (%)	51,05	-	47,17	-	37,94	-
Main cooking energy mixed fuels (%)	25,25	-	27,44	-	29,9	-
Main cooking energy biomass	23,7	-	25,38	-	32,16	-
Explanatory variables						
Economic variables						
Price o firewood/kg	0,89	0,61	1,09	0,73	0,38	0,23
Price of charcoal/kg	1,12	0,50	1,45	0,63	0,67	0,32
Price of kerosene/liter	2,15	0,99	2,50	0,85	2,52	0,91
Price of electricity/kwh	0,38	0,06	0,38	0,05	0,15	0,03
Monthly real consumption/adult eqv. units	153,33	225,39	160,32	164,70	151,22	135,19
Household-level variables						
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
Head, primary schooling completed	0,32	0,47	0,27	0,45	0,30	0,46
Head, junior secondary schooling completed	0,13	0,33	0,15	0,36	0,17	0,37
Head, secondary schooling completed	0,34	0,48	0,18	0,38	0,11	0,31
Head, tertiary schooling completed	0,05	0,21	0,10	0,29	0,12	0,33
Household size	6,05	2,75	5,71	2,69	5,10	2,34
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
City and time dummies						
Addis	0,77	0,42	0,74	0,44	0,59	0,49
Awassa	0,07	0,25	0,09	0,28	0,14	0,34
Dessie	0,08	0,28	0,09	0,28	0,14	0,34
Mekelle	0,08	0,28	0,08	0,28	0,14	0,34
Observations	1093		1115		709	

Table A3. Pooled multinomial logit estimates of household fuel choice

	Mean	SD
Mixed Fuel		
Economic variables		
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
Household-level variables		
Age of head	-0.003	0.004
Head, Male	0.063	0.113
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
Log household size	0.167	0.132
Share of females in household	-0.573**	0.274
Number of children	0.012	0.049
City and time dummies		
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
Biomass Fuel		
Economic variables		
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
Household-level variables		
Age of head	0.004	0.004
Head, Male	0.013	0.130
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
Log household size	-0.552***	0.144
Share of females in household	0.157	0.304
Number of children	0.127**	0.056
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.	
Observations	2917	

Notes: Clean fuel type is base category; ***p<0.01, **p<0.05, *p<0.1