Clean Fuel-Saving Technology Adoption in Urban Ethiopia

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Abstract

The heavy dependence and inefficient utilization of biomass resources have contributed to the depletion of forest resources in Ethiopia, while the use of traditional cooking technology, one source of inefficient biomass resource use, has been linked to indoor air pollution and poor health. In response, the government and other institutions have pushed for the adoption of new cooking technologies. This research examines the speed of adoption of Mirt and Lakech cook stoves – two examples of new cooking technologies – in urban Ethiopia. In terms of the duration analysis, adoption has been increasing over time; income and wealth are important contributors to adoption, and substitute technologies tend to hinder adoption. However, it was not possible to consider prices or perceptions related to either the technologies or biomass availability in the duration models, and, therefore, additional research is needed to inform policy further with respect to household technology adoption decisions.

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1 Introduction

Like many other sub-Saharan African countries, Ethiopia is highly dependent on biomass energy sources, such as fuel wood, charcoal, animal dung and crop residues. These biomass energy sources account for more than 90% of total domestic energy demand, according to the Ethiopian Environmental Protection Agency (EEPA, 2004). The EPA further reports that about 95% of the total population in Ethiopia uses biomass fuels for their main source of energy. Even though urban households have better access to modern energy than the rural population, the difference in biomass use is not large – approximately 99% of rural households compared to 94% of urban households. The heavy dependence and inefficient utilization of biomass resources have contributed to the depletion of forest resources in Ethiopia. In general, Ethiopians are poor, and as noted by Geist and Lambin (2003) as well as Vance and Iovanna (2006), poverty and other socioeconomic factors force people in developing countries, including Ethiopia, to exploit forest resources for both domestic energy consumption and commercial gains. Given the high levels of dependence, biomass will continue to dominate energy demand in both rural and urban Ethiopia in the foreseeable future.

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Ethiopian dependence on biomass fuels impacts on the health of its citizens, especially women and children. The World Health Organization (WHO, 2002) estimates that fumes from indoor biomass cook stoves kill 1.6 million women and children in developing countries, each year, and that the global burden of disease associated with biomass fuel use is 3%. The figures for Ethiopia, though, are proportionately worse. According to the same WHO report, with 95% of households using biomass fuels as their primary energy source, 4.9% of the Ethiopian burden of disease can be attributed to solid fuel use for cooking, heating and lighting; nearly 50,000 deaths can be attributed to the same cause. Some of those health problems are associated with particulate matter that arises from fires.[1] Surveys by Bruce et al. (2002), Smith et al. (2004), Emmelin and Wall (2007) and Fullerton et al. (2008) summarize the strength of association between indoor air pollution – especially biomass fuel use – and a wide range of illnesses and diseases. Associations are shown to exist for acute lower respiratory tract infection, low birth weight, nutritional deficiency, interstitial lung disease, chronic obstructive lung disease and lung cancer, tuberculosis, cardiovascular disease, and cataracts; similar information can be found in WHO (2006). These health problems tend to be greater in areas where traditional cooking technology is more common, as reported by Smith and Mehta (2003), Masera et al. (2007) and Tasleem et al. (2007).

In order to reduce pressure on forests and plantations and mitigate the adverse impact of indoor air pollution, the government has devised a number of strategies. Of particular relevance to this research are the promotion of alternative modern fuels and support for improved biomass cook stoves (Cooke-St. Clair et al., 2008). The Lakech and Mirt stoves, discussed below, are two such examples. The realization that improved cook stove technology has the potential to alleviate the pressure on biomass resources led to improved cooking stove programs in a number of developing countries, including Ethiopia; Barnes et al. (1994) provide an excellent survey of the programs put in place before 1994, as well as the lessons that could be learned from those programs, while Bhattacharya and Abdul-Salam (2002) provide a detailed description of programs in India and China. Similarly, a number of governmental institutions, such as the Ethiopian Rural Energy Development and Promotion Center(EREDPC), and other organizations, such as the Deutsche Gesellshaftfür Technische Zusammenarbeit (GTZ), have been involved in the development and dissemination of different types of biomass cook stove technologies since the early 1970s in Ethiopia (EEPA, 2004). Most recently, in December of 2010, the US EPA and the US Peace Corps signed a Memorandum of Understanding (MoU), and that MoU included support for the Global Alliance for Clean Cook Stoves in Ethiopia.

Unfortunately, as discussed in Barnes et al. (1994) and Shanko et al. (2009), the efforts to disseminate various types of fuel-saving technologies have faced different problems at different times. For example, some of the stove programs were not successful, due to problems related to the stove itself (technical problems); other programs were not successful, due to a lack of understanding of consumer tastes; still other programs were not successful, due to the lack of an appropriate promotion strategy. In addition to implementation problems, there are real concerns that the expected forestry benefits may not obtain. Specifically, the rebound effect – intuitively, better technology results in a decrease in the price of inputs yielding scale effects – has been observed in a number of locations. Nepal et al. (2010), for example, find that improved cook stoves in Nepal do not yield reductions in the demand for firewood. Sorrell et al. (2009) provide a more detailed review of literature in relation to the rebound effect.

Although it is not clear that new cook stove technology will alleviate forest dependence, there is strong evidence of significant potential health benefits that are expected to accrue to households that adopt newer cooking technology. Given the expected household benefits, the recent failures of earlier programs and the renewed emphasis on clean cook stove promotion an examination of adoption decisions at the household level deserves attention. However, most available studies related to technology adoption, especially those related to improved biomass cook stove technologies, such

[1] Etyemezian et al. (2005) note that both PM10 and CO concentrations are highest around 7:00 in Addis Ababa, and that this peak is associated with motor vehicle traffic, food preparation and the heating of homes.

as Amacher et al. (1992), Zenebe et al. (2005) and Inayat (2011), have focused only on the dichotomous decision to adopt new technologies, and not considered the time lag associated with adoption. Although informative, these binary analyses are static and ignore the dynamic nature of the adoption process. Therefore, this research makes two contributions to the literature.

First, the available limited studies focus on rural areas, such that the urban sector is under-represented. However, the high dependence of urban dwellers on biomass resources has also contributed to the current environmental problems in the country. For example, charcoal, the production of which is one of the main causes of deforestation in the country, is almost exclusively used in urban areas, irrespective of the level of living standards. Moreover, since many households cannot afford modern energy sources, such as kerosene, liquefied petroleum gas (LPG) and electricity, a substantial portion of the urban poor will continue to rely on fuel wood and charcoal. Therefore, focusing on urban households is useful, from the viewpoint of protecting forest cover, as well as reducing the ill effects of biomass fuel use on health.

Second, the commonly applied binary dependent variable analysis, which considers only adoption or non-adoption, does not account for adoption over time, since it does not allow for differences in the time to adoption by the households. This analysis, therefore, employs duration analysis, rather than static analysis, and, as far as we are aware, is the first to do so, within the context of improved cook stove technology adoption. The main objective of this research is to examine and understand the determinants of the speed of adoption of fuel-saving technologies, especially for Mirtand Lakech cook stoves, in urban Ethiopia.[2] Though many factors, such as the technical design of the stove, are likely to affect the speed of adoption, the data available for this study allows us only to address socioeconomic factors associated with the dissemination of improved biomass cook stoves in urban Ethiopia.

The analysis unfolds in the usual fashion. The next section, Section 2, describes the methodology. Section 3 discusses the stove technologies examined in the analysis, as well as the data. The results of the empirical analysis are presented in Section 4, while Section 5 concludes.

2 Duration analysis

The analysis of duration data, commonly referred to as survival analysis, has been applied in a number of situations in economics, demography and medicine. In terms of medical research, the focus is mostly on patient survival following disease diagnosis (Brookmeyer et al., 2002), or following the administration of a medical treatment (Locatelli et al., 2001). In demography, survival analysis is often applied in the examination of mortality rates and relates to the length of time a child survives from birth, or the time that a mother survives following childbirth; some examples include Lavy et al.(1996), Abou-Ali(2003) and Handaet al. (2010). Within economics, unemployment duration and the duration of strikes have often been examined via duration models, such as Kennan's (1985) and Jaggia's (1991) analyses of strike duration in the US manufacturing sector. Most relevant to this study, though, is the analysis of technology adoption, such as that by Dadi et al. (2004), Fuglie and Kascak (2001) and Burton et al. (2003), and the adoption of privatization policy analysed by Lee (2003). As argued by Burton et al. (2003) duration analysis has strengths compared with the conventional bivariate approaches. Conventional discrete choice models, such as logit or probit, cannot capture the intertemporal nature of the adoption process. Under these circumstances, the use of duration models is superior to the analysis of adoption at a point in time.

Survival analysis depends primarily on the distribution of durations, or the length of survival times, in the population. Following the standard formulation, let $T \geqslant 0$ denote the duration, while t denotes a particular value of T. In our case, duration is the length of time, measured in years, until the household adopts the new technology.[3] The cumulative distribution function (CDF) of T

[2] Lakech and Mirt are local words meaning excellent and best, respectively.

[3] In our data, the distribution of these times is not normal.

is defined as $F(t) = P(t \leqslant t)$, assuming $t \geqslant 0$. Assuming that T is continuous, the survivor function is defined as $S(t) = 1 - F(t) = P(T > t)$, the probability that the duration will last longer than t, assuming survival up to t.

One of the central concepts in the analysis of duration data is the hazard function. Assuming an individual occupies a given state up to time t, the probability that such an individual exits from the state within an interval Δ, at or after t, is $P(t < T \leqslant t + \Delta | T \geqslant t)$. Therefore, the average probability of leaving the state at or after t, per unit of time period, over a short time interval Δ, can be used to create the hazard function, the average probability over a vanishing time interval. Assuming a differentiable CDF, that hazard function is defined in (1).

$$h(t) = \lim_{\Delta - 0} \frac{P(t < T \leqslant t + \Delta | T \geqslant t)}{\Delta} = \frac{f(t)}{S(t)} \tag{1}$$

As defined before, $S(t)$ is the survival function, while $f(t)$ is the probability density function. The hazard function specifies the instantaneous rate of completion of a spell at $T = t$, conditional upon survival up to time t. It is the rate at which spells will be completed at duration t,given that they last until t. In our case, the hazard function, therefore, represents the probability that a household adopts the improved stove at time t, given that it has not adopted before t.In other words, higher hazard rates indicate higher rates of adoption.

A variety of functional forms have been proposed for duration models; Keifer (1988) presents a very detailed summary of the different distributional assumptions behind these models, such as the logistic, Weibull, exponential, lognormal, and gamma probability distributions. The two most widely used parametric distributions are the exponential distributions and the Weibull distributions. The exponential distribution is characterized by a constant hazard function, $h(t) = \lambda$, where the constant parameter, $\lambda > 0$, implies that the passage of time does not influence the hazard rate. That is, subjects fail at the same rate through time, referred to as memoryless. However, it may be preferable to allow for a hazard with memory. The other commonly applied distribution, the Weibull distribution, is characterised by the hazard function $h(t) = \lambda p t^{p-1}$, with $\lambda > 0$ and $p > 0$. Given the Weibull specification, the hazard rate is constant, monotonically increasing or monotonically decreasing, depending on p. It is monotonically increasing if $p > 1$, and decreasing if $p < 1$. In the case where $p = 1$, the Weibull hazard collapses to the exponential hazard, and is, therefore, constant.

Assuming the duration for each individual, t_i, is independent and not censored, the log-likelihood function for completed spells is given in (2), where $\theta = (\lambda, p)$ is the vector of parameters and X is a matrix of potential time-invariant explanatory variables.

$$\ell(\theta | X) = \sum_{t=1}^{N} \ln f(t_i | \theta, X_i) \tag{2}$$

However, in this analysis, as with most analyses of duration data, there are censored observations, especially right-censored observations. Information on the exact durations is not available for right-censored observations; rather, it is only known that they exceed the observable time horizon. Therefore, the density function in (2) cannot be applied; instead, it must be modified to allow for censoring. Thus, the log-likelihood function contains two components, one for non-censored, $d_i = 1$, observations and another for censored observations, $d_i = 0$; K in (3) represents the number of non-censored observations.

$$\ell(\theta | X) = \sum_{t=1}^{K} d_i \ln f(t_i | \theta, X_i) + \sum_{j=K+1}^{N} (1 - d_i) \ln S(t_i | \theta, X_i) \tag{3}$$

The preceding discussion, although conditioning on additional covariates, has ignored the inclusion of these factors within the likelihood function. Both the exponential and Weibull models are members of the proportional hazards family, which allow for the time component to be separated from the contribution of the other covariates: $h(t, X, \theta, \beta) = h_0(t, \theta)g(X, \beta)$, where β is a vector of parameters to be estimated, h_0 is the baseline hazard, and g is the relative hazard. The most common functional specification for the relative hazard, also used here, is $g(X, \beta) = \exp(X\beta)$; the specification ensures non-negativity of the underlying hazard function. Furthermore, this proportional specification allows for easy interpretation of the results, since the marginal effect of a change in any $X \epsilon X$ is simply the coefficient times the original hazard.[4]

Another member of the proportional hazard family is the Cox (1972) proportional hazard model. One of the most attractive features of Cox's model is that the baseline hazard need not be estimated. Further, it is only assumed that the hazard function is the same for each subject, and that, given the covariates, the hazard between one subject and the other differs only by a multiplicative constant, based on the relative hazard. Given that this model does not specify the underlying hazard, it is also used, below, to check the robustness of the results.

The specifications described up to now assume that all individuals – households, in this case – are identical. However, it is likely that the data do not explain all of the duration behaviour. Importantly, some of the unexplained behaviour could vary across households. This problem, unobserved heterogeneity, can create biases in the estimates, since each individual with the same values of all covariates may have different hazards out of a given state. Mathematically, the easiest solution is to multiplicatively append a stochastic term to the hazard function, $h(t, X, \theta, \beta) = h_0(t, \theta)g(X, \beta)\varepsilon$, and assume a distribution for that stochastic term. One common assumption applied in the literature is that the stochastic term follows the gamma distribution. Below, we consider the Weibull-gamma mixture model, as described in Cameron and Trivedi (2005) and applied by Gutierrez (2002), and test for unobserved heterogeneity in one of the duration models.[5]

3 Analysis data

The data for the analysis come from the 'Mirt Biomass Injera Stoves Market Penetration and Sustainability' study conducted by Megen Power Limited in 2009. The survey was conducted in the Amahra, Oromiya and Tigray Regions. Three towns from each region were selected for the survey. For the purpose of sampling, towns were classified into three categories: High-Sales Towns, Low-Sales Towns, and Non-Project Towns. The sample size for each region and town was determined, proportionately, based on the total number of households. Finally, based on sampling frames (lists of households) obtained from the respective Kebeles, households were selected using a simple random sampling technique. The towns selected for the study are presented in Table 1. Households with and without Mirt biomass injera stoves were included. The number of sampled households was 1577. The questionnaire was further refined prior to fieldwork, through discussion and joint review with enumerators; pre-testing of the questionnaire was undertaken with a few households before the main sample interviews.

3.1 Lakech and Mirt Stoves

Various types of improved biomass cook stoves have been disseminated in both urban and rural Ethiopia. In this analysis, the two most commonly used types of improved stoves, called 'Mirt improved biomass injerastove' and 'Lakech charcoal stove' are discussed. The Mirtstove, which is made from cement and pumice, was designed by the Ethiopian Energy Studies Research Center in the early 1990s; one of their goals was to alleviate environmental degradation (pollution and deforestation or forest degradation). When properly utilized, it serves for approximately 8 years. It is used to cook injera, the staple food of Ethiopia. Injera baking is the most energy-intensive

[4] See Cameron and Trivedi (2005:593) for details.

[5] Unfortunately, the Weibull-gamma mixture model for the Lakech stove duration did not converge, so we were not able to test for unobserved heterogeneity.

activity in Ethiopia, accounting for over 50% of all primary energy consumption in the country, and over 75% of the total energy consumed in households.[6] The Mirt stove has been promoted and widely distributed in the country, because it can achieve fuel efficiency of up to 40% over the open fire stove (Yosef, 2007; Shanko et al., 2009). In addition, the reduction of carbon monoxide (CO) concentration during baking is one of the expected benefits of the technology (Yosef, 2007).However, the reduction in particulate matter (PM), another indoor air pollutant, resulting from the use of the Mirt stove is not significant. According to Yosef (2007) the insignificant reduction in PM could have been due to the small sample used for the study; therefore, improvements in indoor air quality, related to PM and attributable to the Mirt stove, requires additional investigation.

The Lake chcharcoal stove, on the other hand, is made from clay, sand, cement and sheet metal, for cladding. Each Lakech stove saves an average of 75kg of charcoal per household per year.[7] Thus, according to EPA (2004), the Lakech stove yields a 25% savings over the traditional open fire stove. Further, the EPA report suggests that if all Ethiopian rural and urban households (approximately 14.44 million) shift to either the improved Lakech or Mirt stove, a savings of about 7,778,800 tones of fuel wood (requiring the clear-cutting of 137,192.24 ha of forest) will be achieved on an annual basis.

The duration of interest is the length of time it takes a household to adopt either of the two improved biomass cook stove technologies. The start date of each household's duration is defined as the date at which the improved biomass stove was first introduced in the area. According to a report by Shanko et al. (2009), EREDPC first developed the Mirt stove in the early 1990s, while, according to Bess (1998), commercial production of the Lakech stoves began in 1991.[8] Therefore, the dependent variable is the time (in years) households waited before adopting either the Mirt or Lakech stoves, measured by the number of years elapsed since their introduction, which was taken to be 1991 and 1994 for Lakech and Mirt biomass cook stoves, respectively.[9] For households that had not yet adopted, the duration was right-censored at the year of data collection. That is, the date of introduction of the technology (the beginning of the duration) is known, while the end is not, at least for some observations. Note that if the household was formed after the introduction of the technology, duration was calculated from the year the household was formed.[10] The start date is the time when the improved biomass cook stoves were first introduced and the exit date, or the end of the spell, is the time at which the household adopts the fuel-saving technology. In other words, reduced time to failure actually means reduced time to adoption of the technology; the results, below, are interpreted with that feature in mind.

Table 2 shows the adoption proportions of both stoves by sample region. Adoption of the Lakech stove is relatively higher in the Amhara region, followed by Oromiya and Tigray. But the proportion of households adopting the Mirt stove is relatively higher in Oromiya, followed by the Amhara and then Tigray region. There is not much difference in the average time of adoption between the two types of stoves. The predicted (from the Weibull model, discussed below) median time to adoption of the Mirt and Lakech stoves is 15.66 and 16.94 years, respectively.

[6] See http://www.tve.org/ho/series1/reports_7-12/Mirte_Stoves_Ethiopia.html.

[7] Retrieved from http://stoves.bioenergylists.org/stovesdoc/Bess/Mirte.htm. According to Bess (1998),the forest savings from the use of the Lakech was equal to the equivalent of over 2,000 hectares of important dryland forest in Ethiopia.

[8] A few households, in the sample, report purchasing the Lakech charcoal stove before 1991, which should not be; therefore, these households were removed from the analysis. Moreover, some households do not provide a clear purchase year; these households were also removed. A similar strategy was adopted for dealing with the Mirt biomass cook stove.

[9] Different documents report different periods for the introduction of both Mirt and Lakech biomass stoves. Lack of consistency in the various reports made it difficult to define the period of introduction of the fuel-saving technologies. Moreover, there is no information on the specific year for the introduction of each technology in each region. So we take the same year for all surveyed households.

[10] However, the survey does not have any information on the year of marriage or the time the household was formed. We took year of marriage for those households to be year 18 (which is the minimum year for marriage according to the Ethiopian family law).

3.2 Data and Descriptive Statistics

The data also includes information related to each household's socioeconomic characteristics, such as: income; the age, education level, sex and occupation of the household head; type and ownership of improved biomass cook stoves; type and ownership of substitutable cook stoves;[11] children and adults in the household; house ownership and characteristics of the house. Although the initial sample contained 1577 observations, some observations were dropped due to insufficient or missing data. Importantly, households not using biomass for injera baking are omitted. Moreover, household heads reporting their age to be less than 18 are also omitted from the analysis. Thus, the total number of households used in this study is 1557.

Descriptive statistics and the definitions of the explanatory variables are presented in Table 3.[12] Education is expected to affect the adoption decision of many technologies. In this case, educated household heads are assumed to be more aware of the environmental and health effects of using biomass fuels, and, therefore, education is expected to increase the speed of adoption. Given that children and women are the ones most likely to be exposed to the indoor air pollution, female-headed households with children are expected to adopt more quickly than male-headed households with children, household members below the age of 15 years.

In the literature on technology adoption, income is one of the consistently significant determinants of adoption (see, for example, Burton et al., 2003; Fuglie and Kascak, 2001). Although the energy ladder hypothesis[13] argues that increases in income will change household demand for source of energy, Barnes et al. (1994) have argued that the introduction of improved cook stove technology could be a new step in the energy ladder, lying between traditional biomass stoves and modern fuels and appliances. Therefore, we assume that the Barnes et al. (1994) hypothesis holds; wealthier households are able to move up the energy ladder by adopting more efficient technologies. In addition, we include two additional measures of wealth, based on home ownership and the availability of a separate cooking facility.[14] Although such a facility could realistically reduce the health effects of biomass fuel use, and reduce the demand for improved cook stoves, we hypothesize that the wealth effect dominates the health effect, such that households having the ability to access a separate cooking facility are more likely to adopt improved cook stoves.

A number of other variables are likely to affect the speed of adoption of new technologies. For example, household perceptions related to biomass fuel availability, information related to trends in the price of biomass fuels, as well as information related to the price of the Lakech stove, the Mirt stove and other substitute cooking technologies are important determinants of technology adoption and the speed of adoption. However, although the survey included questions related to household perceptions and trends in biomass fuel prices, few households provided answers, and, therefore, it was not possible to include this data in the analysis. Moreover, the responses related to household perceptions of biomass availability do not show significant variation; thus, even if these perceptions were to be included, the results would be insignificant. Unfortunately, the price of the Lakech stove, the Mirt stove and other substitutes are not included, because there is no data available. Moreover, the prices may not reflect the actual market price; the involvement of non-governmental organizations results in market distortions. However, regional dummy variables are included to control for differences in prices and NGO participation in the local markets.

[11] More than 85% of the household who are using electric Mitad have secondary education or above, possibly suggesting that education is important for households to move up the energy ladder. Note that the preparation of injera requires an appliance known as Mitad, a circular clay pan used for baking injera. The electric Mitad is relatively widely used in urban areas.

[12] As expected, the majority of households are dependent on biomass energy sources for baking injera – only 7.8% of the sampled households use electricity for baking injera.

[13] The energy ladder is a concept used to describe the way in which households will move to more sophisticated fuels as their income increases; see Mishra (2008). Roughly, households are assumed to move from fuel wood to kerosene, to LPG and then to natural gas.

[14] Around 72% of the households own their own home, while 75% of them have a separate kitchen for cooking.

4 Results of duration analysis

4.1 Non-parametric Results

Before undertaking parametric duration analysis, a simple test of the effect of income on the survival rate is performed, making use of the Kaplan-Meier estimator (Kiefer, 1988). The Kaplan-Meier estimator is non-parametric, meaning that no assumptions regarding the underlying distribution of survival times are made. The primary advantage of the estimator is that it can easily accommodate right censoring in the data. The estimator requires dividing the period of observation into a series of intervals, each containing one or more adoptions at its beginning. The estimator is essentially the ratio of the number of survivors to the number of observations at risk, in each time interval. Figure 1, below, shows the survival functions for the Mirt and the Lakech stoves by income level, based on the Kaplan-Meier estimator.

In Figure 1, the non-parametric survival function is plotted for each of four different income categories, for both stove types. In all cases, the survival function for income category 1 is higher than the survivor function for category 2, which is higher than that for category 3, which is, in turn, higher than for category 4, where income is highest in category 4 and lowest in category 1. The results suggest that households in the lowest income bracket (less than or equal to 500 Birr) are the least likely and slowest to adopt, while those in the highest income bracket (above 2500 Birr) are the most likely and quickest to adopt. However, a formal test of that relationship is necessary; both the log rank and Wilcoxon test, not reported here, confirm the ranking. Thus, the speed of adoption rises with income.

4.2 Results of Parametric Regression

The remainder of the discussion focuses on parametric duration analysis, in which numerous specifications were estimated. Note that in parametric regressions, right censoring must be accounted for, following equation (6).The appropriateness of the model specifications has also been examined through various diagnostic methods for model specification. The primary diagnostics are based on the results of the Akaike's Information Criterion (AIC) and the Bayesian Information Criterion (BIC). Each of these criteria prefers the Weibull model to the exponential model for both the Mirt biomass stove and the Lakech charcoal stove. Although the information criteria prefer the Weibull model, both the Weibull and exponential model results are presented for comparison purposes.

Another problem in duration analysis, as is true for most statistical analyses, is unobserved heterogeneity, which leads to biased estimates, as discussed in Section 2. Following Gutierrez (2002), the Weibull regression model, with gamma-distributed heterogeneity, is fitted to the data; the fit is accomplished using the frailty (gamma) option to *streg* in STATA. The results of the analysis suggest that frailty, or unobserved heterogeneity, is an important feature of Mirt biomass cook stove adoption decisions.[15]

Tables 4 and 5 present the results of the Weibull estimation for Mirt and Lakech stoves, respectively. A final robustness comparison is also included in the analysis. Since the Cox proportional hazard model does not parameterize the baseline hazard, it is not necessary to specify or estimate the shape of the hazard function. Therefore, the Cox results are robust to misspecification of the hazard function; however, it should also be noted that both the Weibull and exponential models are special cases of the proportional hazard family. With respect to the Lakech charcoal stove adoption analysis, the duration model parameters are qualitatively similar, suggesting that the choice of specification does not have a significant impact on the results, at least within this subset of the family of proportional hazard models.

[15] However, the Lakech charcoal stove duration model with frailty did not converge, and, therefore, unobserved heterogeneity was not included in the analysis.

As noted in Section 2, the hazard rate is assumed to be constant in the exponential model, while, in the Weibull model, the hazard can be monotonically increasing, monotonically decreasing or constant. The results in both Tables 4 and 5 suggest that the estimate of the shape parameter, P, is significantly greater than one, i.e., the hazard is monotonically increasing. In other words, the rate of adoption is increasing, which is not completely surprising. As technology becomes more widespread, its use should become more and more common.

In order to interpret the rest of the results, it is important to recall that a negative estimate implies that failure is less likely, meaning that adoption is less likely, while a positive estimate implies that failure is more likely, meaning that adoption is more likely. For the variables that are measured as categories or levels (income and education), the bottom category was left out to avoid the dummy variable trap. Illiterate is left out in the case of education, while the lowest income bracket is left out, in the case of income. In other words, estimates are relative to the base category.

In terms of the results, both education and income increase adoption rates for the Mirt biomass stove. However, only income increases the speed of Lakech charcoal stove adoption. The results accord with those of Jones (1989), cited in Barnes et al. (1994); middle-income families have adopted improved stoves far more quickly than poor families in most African countries. On the other hand, these income results may also indicate that households will not shift to other, better, sources of energy as their income increases, as postulated by the energy ladder hypothesis, unless we consider the variant of the energy ladder hypothesis proposed by Barnes et al. (1994). Importantly, Masera et al. (2000) note that the original energy ladder hypothesis does not appropriately account for other factors that are likely to affect household switches to modern energy services, such as: affordability, availability, and cultural preferences. Therefore, since the majority of households that depend on biomass are poor, the design and price of new and improved biomass cook stoves should consider poor household capacity to purchase the new technology.

The estimated coefficient for home ownership and separate kitchen facilities suggests that wealth increases the rate of adoption of the Mirt stove, but does not affect the adoption of the Lakech stove. The Mirt stove is a domestic appliance requiring additional space; it is larger in size than many modern and improved biomass cook stoves. Hence, as Shanko et al. (2009) note, its installation and proper utilization requires access to additional facilities. However, the Lakech stove is simple and easily mobile, and, therefore, does not require additional space. As a result, it is not surprising that home ownership and access to a separate kitchen are not significant factors in the adoption of Lakech stoves.

We initially hypothesized that female-headed households with many children would favour adoption of these new cook stove technologies, since both women and children are assumed to be most affected by indoor air pollution. However, the results are not consistent across stove types. Female-headed households are more likely to adopt the Mirt biomass cook stove, while the sex of the household head does not significantly affect the adoption of Lakech charcoal stoves. In terms of children, although the sign does agree with our hypothesis, the effect is insignificant across both types of improved cook stoves. However, this result could be due to the inability, within the data, to separate very young children from older children.

The analysis also included substitute technologies, and their effect on the adoption of Mirt and Lakech stoves. In the analysis, the electric Mitad is assumed to be a substitute for the Mirt stove; however, there is no empirical support for the substitution, possibly, due to differences in relative costs. For example, the relative cost of electric Mitad might be too high, compared with the cost of using the Mirt injera biomass cook stove. Zenebe et al. (2010) find that the high cost of the stove was the main reason for not adopting the electric Mitad stove in the Tigray region in Ethiopia, despite the fact that about 80 percent of sample households used electricity in the region. On the other hand, the metal charcoal stove is assumed to be a substitute for the Lakech charcoal stove, and the results do support the substitution hypothesis. Households with a metal charcoal stove are less likely to adopt the Lakech charcoal stove. Given the better performance of the Lakech stove over the metal stove, reduced adoption rates for substitute stoves, although understandable, implies that additional policies and programs may be needed to increase the rate of adoption of the technically superior Lakech stove.

Finally, as noted above, location variables were included in the analysis to control for effects that differ across regions. The results show that there are regional differences in the speed of adoption of the Mirt stove, but not for the Lakech stove. The speed of adoption of the Mirt stove is lower for households in Amhara and Tigray, compared to households residing in Oromiya. Since the former regions are associated with low levels of biomass, a different result might have been expected. However, if households in the Oromiya region have either better exposure to the new technologies, or face lower prices, due to the level of involvement of NGOs in the region, the result would not be surprising. Unfortunately, our data does not allow us to further test this hypothesis.

5 Conclusions and policy implications

The heavy dependence and inefficient utilization of biomass resources have contributed towards the depletion of the forest resources in Ethiopia. Traditional cooking technologies, one source of inefficient utilization of biomass resources, as well as a source of indoor air pollution and ill health, has led policymakers to seek the advancement of affordable alternative cooking technologies that use fewer resources and result in less pollution. In Ethiopia, two different alternative cook stove options have received the most attention, the Mirt biomass cook stove and the Lakech charcoal stove. Although a number of studies have shown that these stoves use less biomass, and can, thus, be assumed to result in less innocuous health effects, these technologies have not been universally adopted in Ethiopia. This study, therefore, applies duration analysis to examine the adoption of these technologies. The study is underpinned by data recently collected in selected towns in three regions of Ethiopia.

The adoption of improved stoves is important for many stakeholders, including governmental and non-governmental organizations. For example, if richer households adopt more quickly than poorer households, as shown here, then the design and dissemination of the stoves should reflect the interest, or preference, as well as the income level of the household. If, on the other hand, the speed of adoption is affected by the lack of awareness of the potential benefits of these stoves – which could not be considered here – different strategies could be devised to introduce and disseminate the technologies or educate the population about the benefits of these technologies. Examples include dissemination via demonstrations, posters, and radio or TV advertisements. Furthermore, the analysis can provide information for stove producers and other stakeholders regarding the pattern of demand for new stoves and, hence, can be good for production planning. Finally, as already noted, given the importance of reducing the current pressure on biomass resources, increasing land productivity and reducing the ill effects of indoor air pollution, understanding the determinants of adoption, as well as the speed of adoption, can provide information that policymakers can use to increase the speed of adoption, generally.

The results of the analysis support the argument by Barnes et al. (1994), in which energy efficiency might be an intermediate step along the road to more modern energy services. Along these lines, both Mirt and Lakech stove adoption is shown to increase with income. The survival analysis also supports the contention that, as adoption becomes more widespread, rates of adoption tend to increase. Furthermore, substitution, at least in the sense that the alternative is readily accessible, matters. In the case of the Mirt stove, the availability of the electric Mitad alternative does not affect adoptions rates, which could be due to the better performance of the Mirt stove in reducing the energy cost of preparing the staple food, injera. Due to data limitations, our analysis could not speak directly to the reasons as to why households did or did not adopt the various technologies; thus, further analysis is warranted such that policy makers and/or energy planners can further assess the potential impact of electric Mitad stoves, and other improved biomass cook stoves, on overall welfare and biomass use (forest pressure). However, in the case of the Lakech stove, the metal alternative does significantly reduce adoption rates.

Given the importance of the improved stoves in saving biomass resources and reducing indoor air pollution, as well as the inability of this study to control for differences in prices and perceptions related to the benefits of improved cook stove technologies, future research must give more attention to collecting information related to prices, and examine the impact of prices on the adoption of improved biomass cook stoves. However, Muneer and Mohamed's (2003) study in Sudan shows that the convenience of new stoves over the traditional stoves has increased the consumption of fuel wood and/or charcoal. This rebound effect, as it is called, could not be examined here, since data on fuel use was not included in the study. Therefore, future research in this area should also address the rebound potential, by collecting additional data on biomass fuel consumption across households with different types of cook stoves.

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Table 1: Sample Location Information

Region (Total)	**Town**	**Sample size**	**Percent**
Amhara (580)	Bahirdar	424	26.89
36.80%	AmbaGiorgis	60	3.80
	Dagolo	96	6.09
Oromiya(667)	Atnago	66	4.19
42.30%	Goba	409	25.94
	Kofele	192	12.18
Tigray (330)	Hiwane	51	3.23
20.93%	Mehoni	177	11.22
	AdiDaero	102	6.47

Table 2. Mirt and Lakech biomass cook stove adoption by sample region

	TOTAL		**Oromiya**		**Tigray**		**Amhara**	
Variable	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Lakech	0.346	0.476	0.357	0.479	0.201	0.401	0.418	0.494
Mirt	0.254	0.435	0.340	0.474	0.100	0.301	0.243	0.429
Obs	1557		659		329		569	

Table 3: Descriptive statistics of the covariates of fuel-saving technologies and their expected signs (N=1557)

Variable	Mean	S.D.	Min	Max
Sex of HH head (1 if male, and 0 if female) (-)	0.68	0.47	0	1
Age of HH head at the time of the survey(+)	44.88	13.50	18	102
EDUCATION				
Dummy if the household head is illiterate(-)	0.21	0.41	0	1
Dummy if the head can read and write or elementary or junior(1-8)(+)	0.42	0.49	0	1
Dummy if the head is between grade 9 & 12(+)	0.20	0.40	0	1
Dummy if the head has a certificate or above)(+)	0.17	0.37	0	1
Number of children and youths whose age is less than or equal to 15)(+)	1.75	1.54	0	14
Number of adult members of the family)(+/-)	3.38	1.87	1	15
Ownership status of the house (1 if privately owned, and 0 otherwise)(+)	0.72	0.45	0	1
Ownership of separate kitchen (1= Yes , 0 = No)(+)	0.75	0.44	0	1
INCOME (+)				
Monthly income is less than 500 Br(1= Yes , 0 = No)	0.57	0.49	0	1
Monthly income is between 501 & 1499(1= Yes , 0 = No)	0.30	0.46	0	1
Monthly income is between 1500 & 2499 (1=Yes, 0=No)	0.09	0.29	0	1
Monthly income is above 2500 (1= Yes , 0 = No)	0.04	0.20	0	1
A dummy for electric Mitad, a substitute for Mirt (-)	0.08	0.27	0	1
A dummy for Metal stove, a substitute for Lakech (-)	0.48	0.50	0	1
A dummy for clay stove	0.31	0.46	0	1
Dummy Tigray region (+)	0.21	0.41	0	1
Dummy for Amhara region (+)	0.37	0.48	0	1
Dummy for Oromiya region) (-)	0.42	0.49	0	1

NOTE: The signs on the second parenthesis show the expected sign.

Table 4: Determinants of Mirtinjera biomass cook stoves adoption

Variables	Weibull[a] Coef.	Weibull Coef.	Exponential Coef.	Cox Coef.
Sex of HH head	-0.321**	-0.278**	-0.251*	-0.264**
	(0.15)	(-0.13)	(0.13)	(0.13)
Age of HH head	0.006	0.006	0.010**	0.007
	(0.01)	(0.00)	(0.00)	(0.00)
The head can read and write, elementary, junior	0.636***	0.580***	0.558***	0.571***
	(0.22)	(0.20)	(0.20)	(0.20)
The head is between grade 9 & 12	1.240***	1.129***	1.020***	1.096***
	(0.25)	(0.22)	(0.22)	(0.22)
The head has a certificate or above	1.085***	0.984***	0.907***	0.976***
	(0.27)	(0.24)	(0.24)	(0.24)
Number of children and youths	-0.042	-0.038	-0.018	-0.035
	(0.04)	(0.03)	(0.03)	(0.03)
Number of adult members of the family	0.088***	0.076***	0.064***	0.074***
	(0.03)	(0.03)	(0.03)	(0.03)
Ownership status of the house	0.296*	0.240*	0.252*	0.242*
	(0.15)	(0.13)	(0.13)	(0.13)
Possession of electric Mitad	0.206	0.118	0.103	0.132
	(0.20)	(0.16)	(0.16)	(0.16)
Ownership of separate kitchen	0.486***	0.455***	0.436***	0.428***
	(0.17)	(0.15)	(0.15)	(0.15)
Monthly income between Birr 501 & 1499	0.695***	0.619***	0.581***	0.591***
	(0.15)	(0.13)	(0.13)	(0.13)
Monthly income between Birr 1500 & 2499	0.692***	0.641***	0.595***	0.606***
	(0.22)	(0.19)	(0.19)	(0.19)
Monthly income above Birr 2500	1.303***	1.123***	0.982***	1.096***
	(0.30)	(0.23)	(0.23)	(0.23)
Dummy Tigray region	-1.184***	-1.096***	-0.970***	-1.050***
	(0.22)	(0.20)	(0.20)	(0.20)
Dummy for Amhara region	-0.447***	-0.432***	-0.365***	-0.402***
	(0.14)	(0.12)	(0.12)	(0.12)
P – Shape parameter	3.620***	3.291***		
	(0.26)	(0.15)		

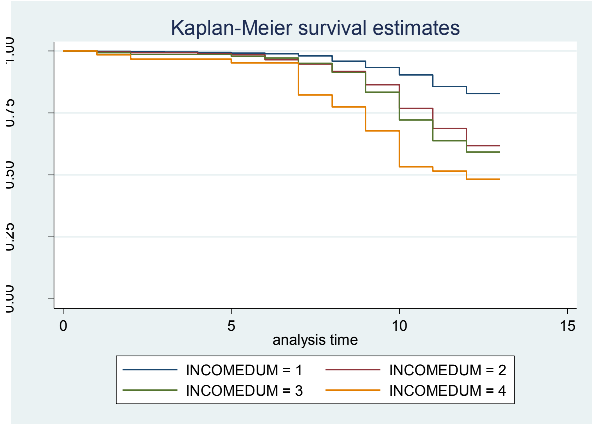
[a] - Weibull regression model, with gamma-distributed heterogeneity using gamma distribution.
* - Significant at 10%; ** - Significant at 5%. *** - Significant at 1%.

Table 5: Determinants of Lakech charcoal stove adoption

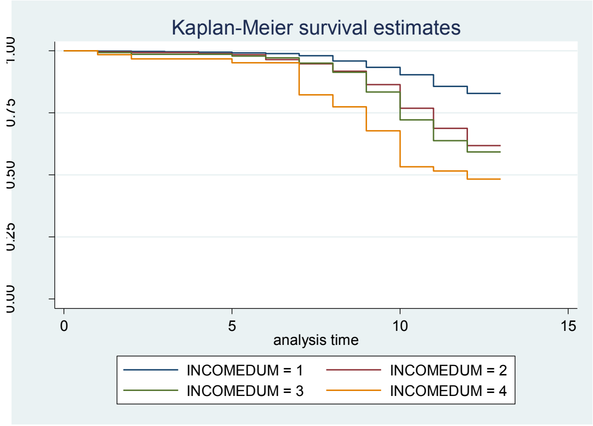
Variables	Weibull	Exponential	Cox
	Coef.	**Coef.**	**Coef.**
Sex of HH head	0.114	0.092	0.100
	(0.11)	(0.11)	(0.11)
Age of HH head	-0.036***	-0.017***	-0.036***
	(0.00)	(0.00)	(0.00)
The head can read and write, elementary, junior	-0.039	-0.012	-0.029
	(0.14)	(0.14)	(0.14)
The head is between grade 9 & 12	-0.015	0.031	0.001
	(0.16)	(0.16)	(0.16)
The head has a certificate or above	0.156	0.197	0.142
	(0.17)	(0.17)	(0.17)
Number of children and youths	-0.043	-0.001	-0.042
	(0.03)	(0.03)	(0.03)
Number of adult members of the family	0.069***	0.061**	0.065***
	(0.02)	(0.02)	(0.02)
Ownership status of the house	0.117	0.124	0.118
	(0.11)	(0.11)	(0.11)
Possession of metal stove	-0.906***	-0.787***	-0.866***
	(0.11)	(0.11)	(0.11)
Ownership of separate kitchen	-0.053	-0.003	-0.056
	(0.11)	(0.11)	(0.11)
Monthly income between Birr 501 & 1499	0.378***	0.356***	0.355***
	(0.11)	(0.11)	(0.11)
Monthly income between Birr 1500 & 2499	0.351**	0.335**	0.339**
	(0.17)	(0.16)	(0.17)
Monthly income above Birr 2500	0.541**	0.507**	0.499**
	(0.22)	(0.21)	(0.22)
Dummy Tigray region	-0.045	-0.031	-0.069
	(0.16)	(0.17)	(0.16)
Dummy for Amhara region	0.044	0.038	-0.003
	(0.10)	(0.10)	(0.10)
P – shape parameter	4.397***		
	(0.17)		

** - Significant at 5%. *** - Significant at 1%.

Figure 1. Survival function for Mirtand Laketch biomass cook stoves



Panel A: Mirt Stove



Panel B: Laketch stove