CHAPTER V

CLEAN FUEL SAVING TECHNOLOGY ADOPTION IN URBAN ETHIOPIA

Abstract

The heavy dependence and inefficient utilization of biomass resources for energy have resulted in high depletion of the 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 some of these technologies – Mirt and Lakech cook stoves – in urban Ethiopia. The duration analysis suggests that adoption rates have been increasing over time, that income and wealth are important contributors to adoption, and that 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, further research is needed in order to further inform policy with respect to household technology adoption decisions.

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 the total domestic energy demand, according to the Ethiopian Environmental Protection Agency (EPA, 2004). The EPA further reports that about 95% of the total population in Ethiopia uses biomass fuels for their main source of energy for cooking, heating and lighting. Even though urban households have better access to commercial energy than the rural population, the difference in biomass use is not large – approximately 99% of rural households and 94% of urban households. Given the high levels of dependence, biomass will continue to dominate energy demand in both rural and urban Ethiopia in the foreseeable future. The heavy dependence and inefficient utilization of biomass resources for energy have resulted in high depletion of the 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, in particular, as well as other socioeconomic factors, result in exploitation of forest resources for domestic energy consumption and commercial gain by the developing world's population.

The developing world's dependence on biomass fuels for energy is associated with 3% of the global burden of disease and 4.9% of the Ethiopian burden of disease, according to the World Health Organization (WHO, 2002).[55] Similarly, particulate matter resulting from fires is associated with a number of other health problems. 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.[56] 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, lung cancer, cardiovascular disease, and cataracts; WHO (2006) provides similar information. Furthermore, the aforementioned health problems tend to be greater in areas in which traditional cooking technology, based on

[55]The World Health Organization (WHO, 2002) estimates that, 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. The WHO also estimates that nearly 50,000 deaths can be attributed to the same cause.

[56] 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.

biomass fuels, are 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 the adverse impact of indoor air pollution, the government has devised supply augmenting strategies and demand management strategies. The supply-side management strategy deals primarily with increasing the availability of fuel wood, through distribution of free seedlings, developing plantations, imposing and enforcing supply restrictions, and the enforcement of property rights. The demand-side management strategies, on the other hand, deal primarily with reducing the demand for biomass energy sources by promoting alternative modern fuels, promoting income growth and increasing the availability of fuel saving technologies, such as improved biomass cooking stoves (Cooke et al., 2008), including the Lakech and Mirt stoves, discussed below.[57]

In December of 2010, the EPA and the US Peace Corps signed a Memorandum of Understanding (MoU), including support for the Global Alliance for Clean Cookstoves in Ethiopia. For Ethiopia, the MoU will result in increased promotion of clean cooking stoves and education related to air quality issues, partly as a response to the burden of disease associated with the use of solid fuels. It is presumed that the large-scale distribution of more efficient stoves will help reduce pressure on biomass resources, increase land productivity – by reducing crop residue and dung usage for fuel – and improve family health. The intervention is expected to benefit women and children, in particular, by reducing fuel collection workloads and limiting exposure to flame hazards and the emission of harmful pollutants.[58]

In order to achieve the expected benefits, sufficient distribution of these improved stoves is necessary, and the preceding MoU could yield positive benefits in this regard. Further, if these benefits can be realized, biomass cook stoves have the potential to significantly contribute to reductions in the demand for biomass resources, while also combating land degradation, thus mitigating the effects of drought, as well as having the potential to yield

[57]The EPA (2004) estimates that if all rural and urban households (estimated to be about 14.44 million) in Ethiopia shift to the improved Lakech and Mirt stoves, 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.
[58]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.

improvements in health. However, Nepal et al. (2010) show that improved cookstoves in Nepal do not yield reductions in the demand for firewood, while Sorrell et al. (2009) provide a summary of literature related to the rebound effect. 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, by recognizing the benefits of improved stoves, a number of governmental institutions, such as the Ethiopian Rural Energy Development and Promotion Center (EREDPC), and other institutions, such as the Deutsche Gesellshaft für 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 (EPA, 2004). However, Barnes et al. (1994) and Shanko et al. (2009), suggest that the efforts by these institutions to disseminate various types of fuel saving technologies have faced different problems at different times. Some of the stoves 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.

Most available studies related to technology adoption, including those related to improved biomass cook stove technologies, such as Amacher et al. (1992), Zenebe et al. (2005) and Inayat (2011), have generally 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, 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 Mirt and Lakech cook stoves, in urban Ethiopia.[59] 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 deals with the method of analysis. Section 3 discusses the stove technologies being examined in the analysis, as well as the data used in the analysis. 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, as well as in 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 Handa et 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),

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

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 anlaysis 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 $T \geq 0$ 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. The cumulative distribution function (CDF) of T is defined as $F(t) = P(T \leq t)$, assuming $t \geq 0$. Assuming that T is continuous, the survivor function is defined as $S(t) = 1 - F(t) = P(T > t)$, the probability that a duration will last longer than time *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 $P(t < T \leq t + \Delta | T \geq t)$. Therefore, the average probability of leaving the state, per unit of time period over a short time interval Δ, at or after *t*, 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).

$$h(t) = \lim_{\Delta \to 0} \frac{P(t < T \leq t + \Delta | T \geq t)}{\Delta} = \frac{f(t)}{S(t)} \qquad (1)$$

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 the case of the adoption of fuel saving technologies, 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 and the hazard function constant. These hazards associated are referred to as memoryless. However, as technologies become more widely available, 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 this hazard function, the hazard rate for the Weibull distribution 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, assuming $\theta = (\lambda, p)$ is the vector of parameters and X is a matrix of potential time invariant explanatory variables, is given in (2).

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

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, only that they exceed the observable time horizon, such that survival to the end of the observable time horizon is known. 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.

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

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 within the structure of the hazard function: $h(t, X, \theta, \beta) = h_0(t, \theta)g(X, \beta)$, 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 is $g(X, \beta) = \exp(X\beta)$, which 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 $x \in X$ is simply the coefficient times the original hazard.[60] That specification is applied in the analysis for both the Weibull and exponential models.

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, the model does not impose any shape on the hazard function. 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 in the analysis 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 available to us does 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

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

model, as described in Cameron and Trivedi (2005) and applied by Gutierrez (2002), and test for unobserved heterogeneity in our duration models.[61]

3. ANALYSIS DATA

The data for the empirical 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 Amahra, Oromiya and Tigray Regions. Three towns from each region were selected for the survey; hence, the total survey was conducted in 9 towns. 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 5.1.

Table 5.1: 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

Both groups of households with and without Mirt biomass injera stoves were included. Accordingly, the Oromiya region was allocated the largest share of the sample, 667 households (42.3%) followed by Amhara with 580 households (36.8%) and Tigray with 330 (20.9%). Therefore, the total number of sample households was 1577. The questionnaire was further refined prior to fieldwork, through discussion and joint review with enumerators; pre-

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

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, we will consider only the two most commonly used types of improved stoves, called 'Mirt improved biomass *injera* stove' and 'Lakech charcoal stove'. The Mirt *injera* stove, 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*, which is the main staple food of Ethiopia. *Injera* baking is the most energy-intensive activity in Ethiopia. It accounts for over 50% of all primary energy consumption in the country, and over 75% of the total energy consumed in households.[62] This 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 due to the small sample used for the study, and, therefore, improvements in indoor air quality due to use of the Mirt stove, in terms of PM, requires additional investigation.

The Lakech charcoal stove, on the other hand, is made from clay, sand, cement and sheet metal for cladding. Each Lakech stove saves an average of 75 kg of charcoal per household per year,[63] thus, according to EPA (2004), providing a 25% savings over the traditional open fire stove. As discussed in the introduction, thousands of hectares of forests can be saved due to the adoption of improved biomass cook stoves, such as the Lakech stove.

In this analysis, 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 date for the start of the

[62] See http://www.tve.org/ho/series1/reports_7-12/Mirte_Stoves_Ethiopia.html.
[63]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.

duration for each household 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 biomass injera stove in the early 1990s, while, according to Bess (1998), commercial production of Lakech charcoal stoves began in 1991.[64] Therefore, the dependent variable used in the analysis is the time (in years) households waited before adopting either Mirt or Lakech improved 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.[65] For those households who had not yet adopted, the duration was right-censored at the year of data collection. That is, we know the period of introduction of the technology (the beginning of the duration), but we do not know the end 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.[66] 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 5.2 shows the adoption proportions of both stoves by sample region. Adoption of Lakech charcoal stove is relatively higher in Amhara region followed by Oromiya and Tigray. But the proportion of households who adopted Mirt injera cook stove is relatively higher in Oromiya, followed by Amhara and then Tigray region. There is not much difference in the average time of adoption between the two types of stoves. The median time of adoption of Mirt and Lakech predicted, for example, by the Weibull distribution, results discussed below, is 15.66 and 16.94 years, respectively.

---

[64] 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.

[65] 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.

[66] 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).

Table 5.2. 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	

3.2. Summary statistics of analysis data

The data also includes information related to each household's socioeconomic characteristics, such as: income; the age, education level, gender and occupation of the household head; type and ownership of improved biomass cook stoves; type and ownership of substitutable cook stoves;[67] 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 (13 households) are omitted. Moreover, household heads reporting their age to be less than 18 (two in number) 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 included in the analysis are presented in Table 5.3.[68] 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, we expect education 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. In this analysis, children are all household members below the age of 15 years.

[67] 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.

[68] 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.

Table 5.3: Descriptive statistics of the covariates of fuel saving technologies

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 1 if the household head is illiterate, 0 otherwise	0.21	0.41	0	1
Dummy 1 if the head can read and write or elementary or junior(1-8), 0 otherwise	0.42	0.49	0	1
Dummy 1 if the head is between grade 9 & 12, 0 otherwise	0.20	0.40	0	1
Dummy 1 if the head has a certificate or above), 0 otherwise	0.17	0.37	0	1
Number of children 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 (1 if the hh has electric Mitad and 0 otherwise)	0.08	0.27	0	1
A dummy for Metal stove, a substitute for Lakech (if the HH has metal charcoal stove, 0 otherwise)	0.48	0.50	0	1
A dummy for clay stove (if the HH has clay stove, 0 otherwise)	0.31	0.46	0	1
Dummy Tigray region (1 if Tigray, 0 otherwise)	0.21	0.41	0	1
Dummy for Amhara region (1 if Amhara and 0 if not)	0.37	0.48	0	1
Dummy for Oromiya region) (1 if Oromiya, 0 if not)	0.42	0.49	0	1

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

In the literature on technology adoption, income is one of the consistently significant factors determining household decisions to adopt new technologies (see, for example, Burton et al., 2003; Fuglie and Kascak, 2001). Although the energy ladder hypothesis[69] 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 the modern fuels and appliances. Therefore, we assume that the Barnes et al. (1994) hypothesis holds, such that wealthier households are able to move up the energy ladder by adopting more efficient technologies, since households with high incomes are more able to afford such purchases. In

[69]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 and electricity.

addition, we include two additional measures of wealth, based on the ownership of their own home and the availability of a separate cooking facility.[70] 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, we expect that 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 Lakech, Mirt and 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 both Lakech and Mirt injera biomass cook stoves and the price of substitutes (other similar stoves serving the same purpose) are not included, because there is no data available. Moreover, the prices may not reflect the actual market price, since the involvement of non-governmental organizations results in market distortions. However, we have included regional dummy variables to control for differences in prices and NGO participation in the local markets.

4. RESULTS OF DURATION ANALYSIS

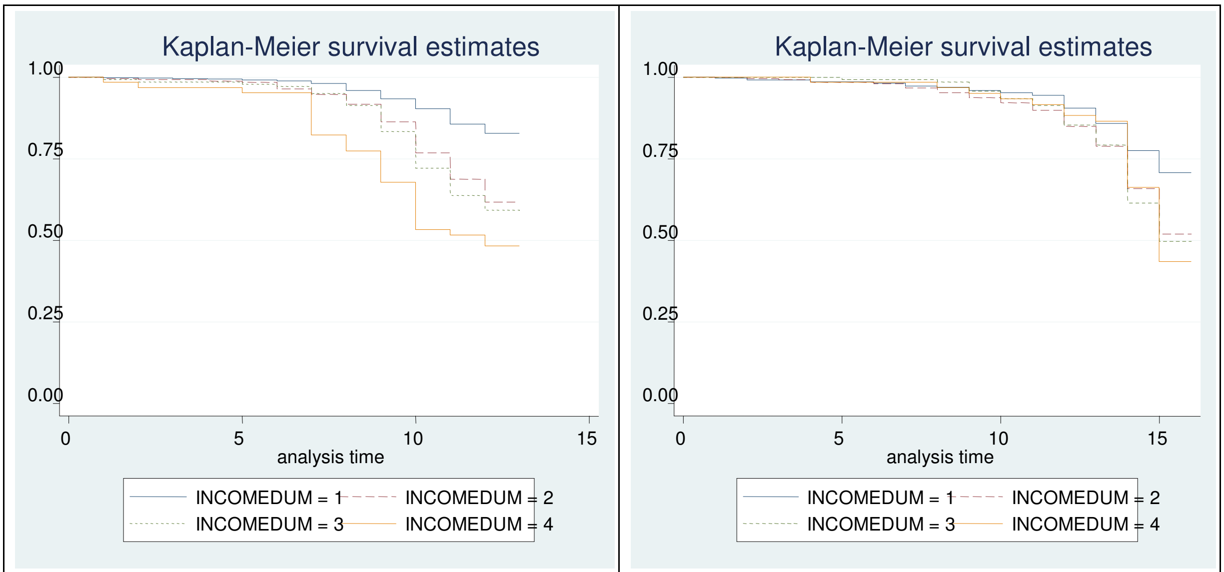
4.1. Nonparametric Results

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 number of survivors to the number of

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

observations at risk, in each time interval. Figure 1, below, shows the survival functions for the Mirt biomass injera stoves by income level, based on the Kaplan-Meier estimator.

In Figure 5.1, the non-parametric survival function is plotted for each of four different income categories, for both stove types. As can easily be seen, 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 logrank and Wilcoxon test confirm the ranking; thus the speed of adoption rises with income level.[71]



Panel A: Mirt Stove

Panel B: Laketch stove

Figure 5.1. Survival function for Mirt and Lakech biomass cook stoves

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).[72] The appropriateness of the model specifications has also been examined through various diagnostic methods for model specification. The primary

[71]The tests reject equality at the 1% significance level. The results of these tests for the Lakech stove are similar, and not reported, but available from the authors upon request.

[72] In STATA, this is accomplished by setting the data to be survival time data and accounting for event failures.

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, we report the results of both the Weibull and exponential models for comparison purposes.[73]

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 using the frailty (gamma) option to streg in STATA, is fitted to the data. The results of the analysis suggest that frailty, or unobserved heterogeneity, is an important feature of Mirt biomass cook stove adoption decisions.[74]

Tables 5.4 and 5.5 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.

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 5.4 and 5.5 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.

---

[73] A Cox proportional hazards model was also estimated, and these results are also presented.
[74] However, the Lakech charcoal stove duration model with frailty did not converge, and, therefore, unobserved heterogeneity was not included in the analysis.

Table 5.4: Determinants of Mirt injera biomass cook stoves adoption

	Weibull*	Weibull	Exponential	Cox
Variables	Coef.	Coef.	Coef.	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 is between 501 & 1499	0.695***	0.619***	0.581***	0.591***
	(0.15)	(0.13)	(0.13)	(0.13)
Monthly income is between 1500 & 2499	0.692***	0.641***	0.595***	0.606***
	(0.22)	(0.19)	(0.19)	(0.19)
Monthly income is above 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)
_cons	-11.995***	-11.13***	-5.559***	
	(0.76)	(0.52)	(0.35)	
/ln_p	1.287***	1.191***		
	(0.07)	(0.05)		
/ln_the	-0.343			
	(0.61)			
p	3.620	3.291		
	(0.26)	(0.15)		
1/p	0.276	0.304		
	(0.02)	(0.01)		
theta	0.710			
	(0.43)			

*Weibull regression model, with gamma-distributed heterogeneity using gamma distribution.
Likelihood-ratio test of theta=0: chibar2(01) = 3.05 Prob>= chibar2 = 0.040. The definition of the dummy variables is presented in table 5.3.

Table 5.5: Determinants of Lakech charcoal stove adoption

	Weibull	Exponential	Cox
Variables	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 is between 501 & 1499	0.378***	0.356***	0.355***
	(0.11)	(0.11)	(0.11)
Monthly income is between 1500 & 2499	0.351**	0.335**	0.339**
	(0.17)	(0.16)	(0.17)
Monthly income is above 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)
_cons	-11.391***	-3.236***	
	(0.52)	(0.26)	
/ln_p	1.481***		
	(0.04)		
p	4.397		
	(0.17)		
1/p	0.227		
	(0.01)		

Note that the frailty model do not converge in all the specifications of Lakech charcoal stoves. The definition of the dummy variables is presented in table 5.3.

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. For the variables that are measured as categories or levels (income and education), the bottom category was left out, illiterate in the case of education and the lowest income bracket in the case of income, to avoid the dummy variable trap, yielding estimates that are relative to the base category. In terms of our 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 households 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 Biomass injera stove, but does not affect the adoption of the Lakech charcoal stove. Mirt is a domestic appliance requiring additional space, due to the fact that 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 charcoal 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 gender 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, although this result could be due to the inability to separate very young children from older children in the analysis

The analysis also included substitute technologies, and their effect on the adoption of Mirt and Lakech cook stoves. In the analysis, the electric Mitad is assumed to be a substitute for the Mirt stove; however, the empirical results do not support the hypothesis that the availability and use of substitute technologies will reduce the speed of adoption of other related technologies. Possibly, the result is due to differences in relative costs. For example, the relative cost of using 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. Another possible justification for this is that the two stoves use different fuel type (i.e. biomass and electricity). Hence the unreliability of power supply in the country may also force some households to possess Mirt *injera* stove. 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 that of the metal stove, this reduced adoption rates for substitute stoves, although understandable, implies that additional policies and programs may need to be put in place 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, the result would be justified 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. 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 for energy have resulted in high 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 associated with the inhalation of smoke, 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 resources, and can, thus, be assumed to result in less innocuous health effects, these technologies have not been universally adopted in Ethiopia. This study, therefore, examines the adoption of these technologies through the application of duration analysis to data recently collected in selected towns in three regions of Ethiopia to understand the determinants of adoption.

The analysis of the speed of adoption of improved stoves is important for many stakeholders, both governmental and non-governmental organizations, in many ways. 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, due to inconsistencies in the data, it is likely that different strategies could be devised to introduce and disseminate the technologies, or at least educate the population about the benefits of these technologies 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 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 policy makers can use to increase the speed of adoption.

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. Similarly, since lower income households are less likely to adopt these more efficient cooking technologies, the research also suggests that other policy options must be implemented, most likely policies to reduce the initial purchase price, if adoption rates are to be increased. 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, in order to determine whether or not the presumed reductions in forest degradation can be realized through the adoption of energy saving technologies, such as improved biomass cook stoves.

CHAPTER VI
SUMMARY AND CONCLUSIONS

Ethiopia is endowed with different types of natural resources. Forests are vital for the welfare of tens of million of Africans, especially the poor and marginalized, and over two thirds of the world's population rely directly or indirectly on forests for their livelihoods (CIFOR, 2004). The reliance of poor people on natural resources for survival, leads to depletion of resources and exacerbating environmental stresses. Since the majority of the population in Ethiopia are rural households (85%), the management and use of these resources directly affects the lives of the people. Many depend on forests for fuel wood, timber, food, grazing, shade, medicinal values, etc. However, the proportion of land with forest cover has been diminishing at an alarming rate. Land area covered by forests has gone down from approximately 40% at the turn of the century to approximately 3.6% at the present time (WBISPP, 2004). Although reliable statistics are absent, a widely quoted estimate indicates that the deforestation rate in Ethiopia ranges between 150,000-200,000 ha per year. Depletion of these resources have resulted in reduced agricultural productivity and subsequently in reduced quality of life of the rural people (EPA, 1998).

In the literature various factors are mentioned as causes of forest degradation and/or deforestation in developing countries. According to the world Growth report (2009), conversion of forests to other land uses, particularly for agricultural expansion and acquisition of fuel wood is generally recognized as the main driver of land-use change and deforestation in the developing world. In Africa illegal logging, fire, fuel wood collection, and shifting cultivation are the four main reasons but their importance varies between countries (FAO, 2009). The demand for agricultural land, fuel wood, construction materials, and policy failure and institutional factors are the main drivers of the change in the forests cover in Ethiopia. Poverty also plays a major role in the current environmental degradation problem in Ethiopia as in many other developing countries.

Despite the importance of forests and forest products to the livelihood of the people, empirical evidences on the forest people interaction are still scanty in Africa in general and Ethiopia in particular. Cavendish (2000) has also explained that we do not have enough empirical evidences on the interaction between natural resources and people in Africa. This is because data on environmental resources in Africa is generally absent as survey data collection on environmentally resources is costly (Cavendish, 2000). A detail review by Cooke et al. (2008) on fuel wood related studies conducted in various parts of Asia and Africa clearly indicated that there are very limited empirical evidences on the nature of the link between consumption, production and households' behaviour towards fuel wood scarcity in developing countries. Rigorous empirical evidences on the link between people's livelihood and forest degradation are still scanty. The limited available empirical evidences are not consistent and convey mixed results. Understanding this gap, this thesis focuses on investigating the relationship between rural household energy use and forest degradation, and empirically examine and understand the link between local level institutions, property rights and forest dependency. Moreover, the determinants of one of the demand side approaches, adoption of fuel saving technologies, were also examined in urban Ethiopia. Therefore, the thesis has tried to address the following issues: How do people respond when faced with scarcity of environmental goods (fuel wood) under different environmental conditions? What are the socioeconomic and environmental factors that affect the preference of rural households to collect forest resource (fuel wood) from a particular source? How is the level of dependence of these households on forest products and what factors determine the amount of income derived from forest resources? How is the nature of the link between different property right regimes and use of forest resources? Are local level institutions affecting the use of forest products, especially non wood forest products in rural Ethiopia? Finally, the thesis addresses the socioeconomic and environmental factors that help to speed up the adoption of fuel saving technologies in urban Ethiopia.

This study has contributed to the literature in many ways. First, it tries to examine the response of rural households by classifying the study area in to low and high forest cover regions. Many studies do not link the fuel wood problem with the state of forests. This study used GIS data to relate forest degradation level with the coping mechanisms of rural households when faced with fuel wood shortages. Second, it adds to the limited empirical literature on the role and determinants of forest dependency by emphasizing the role of local level institutions and property right regimes. Here the role of forest products in the livelihood of the people and the various socioeconomic and environmental factors that affect forest dependency in rural Ethiopia are analysed by using appropriate econometric strategies. Third, it applies duration econometrics to the analysis of the adoption of biomass cook stoves in Ethiopia. Last, each chapter in the thesis adds to the limited empirical studies in Africa in general. Most available studies focus on few countries in Asia and additional studies from other countries in other regions will help to make inference about the forest people interaction (Cooke et al., 2008).

In order to address the various issues indicated above, household survey data collected in different pars of the country (urban and rural) were used for the empirical analysis. Sample households were chosen based on a simple random sampling technique. In addition, community level surveys were also gathered to get villagers' attitude and perceptions on their local forest management, and use. Secondary information from various government organizations was also collected. A different household survey data conducted in different towns of the country was used for the analysis of covariates of fuel saving technologies in urban Ethiopia.

To achieve the above stated objectives this study combined various approaches. The theoretical framework is based on farm household model that assumes that both production and consumption decision of the household are inseparable. The random utility framework was employed for the analysis of the choice of fuel wood sources. Empirically, the thesis employed different econometric models depending on the nature of the problem to be addressed. Econometric models such as Heckman sample selection, discrete choice model, OLS and duration econometrics were employed for the empirical analysis. Finally, based on the results of the empirical analysis**,** important findings and policy implications from each chapter are discussed. At the end, issues for further research in related areas are also highlighted.

The empirical part of the thesis starts with analysing the coping mechanisms of rural households to fuel wood scarcity by using a survey of randomly selected rural households in Ethiopia. As described earlier, as opposed to most other studies, it uses information from a GIS survey to classify the study area into relatively low and high forest cover regions. Rural household's behaviour towards fuel wood was examined separately for relatively low forest cover and high forest cover areas, while pooled regressions were considered for the collection or production of other biomass sources, i.e., dung and crop residues.

The results of the empirical analysis show that rural households residing in forest degraded areas respond to fuel wood shortages by increasing their labour input to fuel wood collection.

However, households in HFC areas respond neither to the physical measure nor to economic measure of fuel wood scarcity. For households in HFC regions forest stock (negatively) and biomass availability (positively) may be more important factors than scarcity of fuel wood in determining household labour input allocation. The study also finds that there is no evidence for substitution between fuel wood and dung or fuel wood and crop residues. The implication of our finding is that supply-side strategies, alone, may not be effective, if the aim is to reduce forest degradation and biodiversity losses, and simultaneously increase the supply of dung and residues for soil management. Any policy intervention that adopts demand side strategies (for example, adoption of improved biomass cook stoves) should give priority to the relatively forest degraded areas in order to reduce fuel wood consumption (and hence decrease the burden of the household) and release dung and residues to the soil for agriculture. Population pressure in all regions, in general, and in LFC regions, in particular, contributes to forest degradation and a loss of biodiversity, in rural Ethiopia, where encroachments for agriculture and grazing are common. As explained by Heltberg et al. (2000), the underlying factors responsible for forest degradation or deforestation in the area need to be addressed if specific forest policies, such as afforestation and area enclosure establishments, are to be effective at the local level. Moreover, specific forest polices on increasing forest stock will be more effective if it takes into account the population pressure in the local area. We have also learned that rural households behaviour in the use of natural resources in general and fuel wood in particular varies in different level of forest degradation. The implication is that policy instruments that are designed to reduce forest degradation and deforestation and improve the forest status of the country should consider the role of agro-ecological and geographical factors. Instead of a one-size-fits-all approach, policy makers need to address environmental degradation problems based on the specific environmental conditions of each region.

Standard household characteristics were also included and results were discussed in this thesis. We found that the age, sex and education level of the household head (except for HFC areas) do not affect the time spent in fuel wood collection. The findings indicates that it is necessary to increase the level of awareness of the people in order to reduce consumption of energy sources such as dung and crop residues. As increasing scarcity of fuel wood does not induce households to shift to other lower quality energy sources, we argue that, as opposed to the energy ladder hypothesis, dung and residues are not perceived as inferior goods in this sample of Ethiopian households.

In addition to the above suggestions, planners need to give more attention to the open access nature of forests in the country. Rural households collect forest products from different sources i.e. either from private, community, state (*de facto* open access). Identifying the factors that drive households to collect forest products, fuel wood in this case, especially from open access sources is very important from the point of forest conservation and enhancing the contribution of forests to the livelihoods of rural people, as well as keeping their ecological functions. With this in mind the third chapter of this thesis deals with property rights and the choice of fuel wood sources in rural Ethiopia using a discrete choice model, multinomial logit regression, developed within the context of random utility. The results of the empirical analysis show that active local level institutions reduce dependency on community forests, but are positively correlated with the decision to collect from open access areas. With respect to policy, the results are positive, in the sense that the demand for community forests resources appears to be lowered by community forestry institutions, the results are also negative, in the sense that the demand for open access forest resources rises, in the face of better community forestry institutions. In other words, there is a need to bring additional open access forests under the management of the community and increase local awareness regarding the use and rules associated with forestry management.

The impact of tenure security (land certification) was also included and found not to have any impact on household's decision to collect from private sources. Although the literature suggests that land certification is responsible for increased investment in the land's productivity, through better soil conservation and the planting of trees (Deiningeret al., 2009; Holden et al., 2009), our results suggest that these investments have, as yet, not resulted in significantly increased use of private forests for fuel wood. However, additional empirical research on the role of land certification, as well as farmers' investment and use decisions may be required to supplement these findings.

Other household characteristics such as education, land size, the number of livestock, and distance to forest were also included to examine their effect on the choice of fuel wood sources. Regional variation also matters for the choice of fuel wood sources, which suggests that promotion of tree planting as a source of fuel wood may be more successful in a relatively degraded environment or fuel wood shortage is a concern.

As repeatedly mentioned in the thesis, forests in addition to fuel wood provide many other non timber or non wood forest products. Different studies such as Fisher (2004), Cavendish (2000), Angelsen and Wunder (2003) indicated the importance of non timber forest products in the livelihood of the people in many developing countries. As a result many efforts are being undertaken to sustain the forestry sector and hence increase the benefits obtained from the sector. This will in turn enhance the poverty alleviation efforts of the country. As has been stated and described earlier, the low and decreasing forest cover in Ethiopia is due to, among other factors, policy failure. For example, forests are typically owned and managed by federal and regional governments. This will lead to more deforestation and forest degradation as this may, among other things, create a property right regime closer to open access (Mekonnen and Bluffstone, 2008). Several studies have reported that devolution of forest management to the local people improves the forest cover and biophysical conditions thereby providing economic benefits to the local people. Though the management of common property resources (CPRs) and the implications for environment and poverty have been relatively well studied in India and Nepal, there are no such systematic studies in Ethiopia. In this regard additional empirical evidences would help policy makers understand the role of forest products in the current poverty alleviation efforts in the country. A full understanding of the relationship between local level institutions, resource use patterns and forest management will be a major step toward formulating policies and programs that aim to increase equity and enhancing the sustainability of resource base at the community level.

In chapter four of this thesis, we have examined the role of local level institutions and property right regimes on the level of forest dependency. Forest products are important in the study area and farm households collect them from different sources. In line with other similar studies (e.g. Mamo et al., 2006) forest products contribute, on average, 8.7 percent of total income of households in our study area and this can go up to 41 percent for some households. This is obtained by taking only non wood forest products. Including the contribution of fuel wood and charcoal would further increase the contribution of all forest products. The study, as also agreed by some scholars, is another evidence to argue that forests can play an important role to poverty alleviation and food security in Africa including Ethiopia.. This indicates that more emphasis need to be given to the management of forests as they contribute significantly to the livelihood of the people especially the poor. Moreover, with proper management it is possible to keep the environmental and ecological benefits from forests.

The results of the analysis suggest that the level and contribution of forest products to the livelihood of the people depend on so many factors such as household demographic and socioeconomic characteristics, institutional and environmental factors. Forest dependency is negatively related to the wealth status (using livestock and land as indicator) of the household. On the other hand, forest resource use from open access areas are positively correlated with wealth suggesting that there is a need to expand the current practice of participatory forest management (PFM) to other open access forest areas. In line with the above argument, it is necessary to identify the constraints for rural households to participate in community forestry. The role of local institutions and socioeconomic characteristics of households on forest dependency in a community forests were also examined. The findings show that local level institutions are not significant factors in determining the use of non-wood forest products, unlike major forest products such as timber or woody materials in general. However, we cannot conclude that local level institutions are not important for proper natural resource management. Importantly, institutional conditions are well understood by the PFM participants, meaning that households are fully aware of the forest use rules, regulations and management policies of the community forest. Finally, we conclude that generalization on the forest-poverty link depends on the type of forest management and the specific characteristics that prevail in the area. These results are suggestive for policy. Improving property rights, either through community forestry or private ownership, is likely to reduce the exploitation of forest resources, and may provide equity benefits for the rural population. Moreover, with such measures, it is possible to maintain, or even improve, the environmental and ecological services provided by forests. In this regard, the distribution of seedlings and provision of technical assistance to rural households could also be beneficial, although such activities could not be addressed in this study.

In order to sustain the contribution and maintain the ecological functions of forests, it must be managed in a more holistic manner. Ethiopia follows both a demand side and supply side strategies to solve the problem of the forestry sector which is under serious threat currently. Tree planting, strengthening property rights, plantation, etc are the supply side strategies while reducing the demand for fuel through the dissemination of energy efficient technologies such as improved biomass cook stoves and transition to other fuel types are the demand side strategies employed to address the aforementioned problems related to forestry in the country. While these strategies can be applied in both rural and urban areas, the role of the urban population in the current environmental problem is usually given less attention. That means the importance of forests and causes for forest degradation and deforestation is usually linked with the rural people in Africa including Ethiopia. However, the urban population in many developing countries including Ethiopia also contribute to the environmental problem as they depend on biomass energy sources such as charcoal, fuel wood, and construction materials. Various governments and non-government organizations are trying to address the problem through the introduction and dissemination of different types of fuel saving technologies. Although a number of studies have shown that these stoves use less biomass resources, and can, thus, be assumed to result in less innocuous health effects, these technologies have not been universally adopted in Ethiopia. Moreover, households take different amounts of time to adopt the technology. By recognizing the role of urban population in the current environmental problem of the country, this thesis also emphasize the need to adopt energy efficient technologies such as improved biomass cook stoves in both rural and urban Ethiopia. Therefore, we have tried to examine and understand the determinants of the speed of adoption of fuel saving technologies in urban Ethiopia by using data collected from selected towns in three regions of the country.

We were able to identify several socioeconomic, geographic and substitute technologies important to the speed of adoption of fuel saving technologies (Mirt biomass *injera* stove and Lakech charcoal stove). The results show that both Mirt and Lakech stove adoption increase with income. Similarly, since lower income households are less likely to adopt these more efficient cooking technologies **,** the research also suggests that other policy options must be implemented, most likely policies to reduce the initial purchase price, if adoption rates are to be increased. Education is positively and significantly related to the speed of adoption of Mirt biomass cook stoves but its effect on the adoption of Lakech charcoal stove is insignificant. The impacts of substitute technologies were also examined. We found that the possession of Electric Mitad (a substitute for Mirt *injera* stove) does not have any effect on the adoption decision of Mirt biomass cook stoves, which may be due to the better performance of Mirt in reducing the energy cost of preparing the staple food, *injera*. However, in the case of the Lakech stove, the metal alternative does significantly reduce adoption rates. This may suggest that there is a need to reconsider the promotion strategy given the better performance of Lakech charcoal stove over Metal charcoal stove. The findings further show that the probability of adoption of Mirt biomass cook stoves will increase for households with private houses and separate kitchen facilities for cooking. Other household characteristics, such as the age and gender of the household head, the number of adults, and the number of children and youths were also important factors in the adoption decision of the improved biomass cook stoves. Finally, we argue that any forest or energy policy that tries to solve the problem of the forestry sector should also address the roles and contributions of the urban population.

In conclusion, sustainably managed forestry provides positive economic and environmental benefits. The results from this study provide valuable insight for Ethiopia's current demand-side and supply-side strategies for addressing rural energy problems, especially policies related to forests and forest resource conservation, as well as halting, and hopefully reversing, the unsustainable use and exploitation of those resources. In order to maintain this, the thesis suggests that no single strategy will work for Ethiopia. We need to approach the problems of forest degradation and deforestation from both rural and urban side; demand as well as supply side. In addition, the findings of this research can be considered as a basis for similar analysis in other African countries in particular and developing countries in general.

Further research may focus on the following issues: With regard to the discussion in chapter two, further research may focus on analyzing whether the increase in labour inputs comes at the expense of other productive activities such as agricultural production in forest degraded regions. In addition, one can examine the relationship between different groups of households and forest scarcity in environmentally degraded regions. In line with chapter three of this thesis, we suggest further research on evaluation of the long-term effect of land tenure security (land certification) on farmers' investment decision and the implication of this on rural energy and forest degradation in the region. As a continuation of chapter IV, analysing and understanding the nature of the link between forest resource uses, institutions and household wellbeing over time will enable us to understand the dynamic aspect. This, however, may be very difficult in many sub-Saharan African countries, as it demands more resources. Finally, our last chapter of the empirical analysis focuses on the adoption decision of fuel saving technologies, but not the efficient use. Future research should examine the quantity of fuel wood and charcoal that were saved, due to these improved biomass cook stoves. 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 and perceptions on the adoption of improved biomass cook stoves. Contrary to the argument on the benefits of these technologies, some literature indicated that the convenience of some improved biomass stoves has increased consumption of biomass fuels, called the 'rebound effect'. Whether this is the case in Ethiopia should also be addressed, by collecting additional data on biomass fuel consumption across households with different types of cook stoves, in order to determine whether or not the presumed reductions in forest degradation can be realized through the adoption of energy saving technologies, such as improved biomass cook stoves.