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FUELWOOD CONSUMPTION AND FOREST DEGRADATION IN RURAL HIGHLANDS OF ETHIOPIA: THE CASE OF AMHARA REGION

BY
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Fuel Wood Consumption and Forest Degradation in Rural Highlands of Ethiopia: The Case of Amhara Region

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ABSTRACT

The paper examines the energy supply demand in Highland rural Ethiopia- the case of Amhara Region. We develop a non-separable household model to analyze the link between forest scarcity and household energy consumption, focusing on the substitution of fuels from the forests and commons and the private domain.

The model is estimated by Two Stage Least Squares using recently collected data from 12 rural kebeles of East Gojam and South Wollo in the Amhara region. To check and correct (when necessary) for sample selection bias due to unobsevabiltiy of the amount of fuel collected for non-collecting household, Heckit model was used.

Fuel collections in the study area significantly respond to fuelwood collection time, household endowment profiles, and household demographic characteristics. The results showed that households are responsive to fuelwood scarcity. The relative scarcity of private energy in the model was captured by the effect of non-price variables including number of trees growing on own field, animal stock, and farm size on this fuel type. Households that are better off in owning large farmland size, large number of trees, and cattle have an advantage to collect more fuel from private domain.

The cross price elasticities of the above variables showed that fuelwood from commons and the alternative domestic fuel (i.e. private energy) are gross substitutes. Many of the implied elasticities were, however, low. Thus, policy interventions appear necessary to reduce forest degradation.

1. INTRODUCTION

1.1 General Background

Energy plays a vital role in supporting efforts to improve the living standard of people across the world. People need energy for the services it can provide. People need the wide range of 'energy services' - cooking, heating, lighting, transport, communication, refrigeration etc - that have critical impacts in facilitating sustainable livelihoods, improving health and significantly reducing poverty. In order to satisfy the need for these energy services, people use several kinds of equipment that use energy.

Economic base of a country or individuals determines the type of equipment or energy sources the individuals consume. The patterns of energy consumption practiced in any country, on the other, have an effect on the welfare of individuals [Reddy 2000]. Today there is a mounting argument that poverty reduction and development programs of developing countries to be reliant on 'universal access to energy services that are affordable, reliable, and of good quality' [Reddy, 2000: 40].

To meet their energy demand, the majority of the people living in developing countries depend on the use of natural resources from their local environment. Nearly two billion of the total population has no access to electricity, gas and oil to cook their food [World Bank 1996]. Regarding peoples' dependency on primary products as source of energy, the situation is more serious and evident in Africa. The dependency of Africa on natural resource for energy is highest in the world. About 67% of primary energy consumption in the continent comes from fuelwood and charcoal [Davidson and Sokona, 2002].

It would not be an overstatement if we propose that fuelwood, as source of traditional energy, has remained the central part of life in developing countries. Such centrality of fuelwood use has more preponderant in rural areas.

Fuelwood collection and deforestation have a two-way relationship. On the one hand, demand for fuelwood causes resource degradation to the extent that collection exceeds sustainable yield. Forest degradation, on the other leads to a situation of fuelwood scarcity. In addition to the fuel related problems there are other serious costs resulted from forest degradation. Soil erosion, loss of biodiversity, and release of carbon dioxide into the atmosphere are other adverse consequences of forest degradation [Heltberg et al., 1998]. An occurrence of such situation is more pronounced to affect the poor [Serra, 1996].

Of particular interest, and an important issue, of fuelwood usage in rural area concerns its link with poverty. Given poor households, the attributes to the ways in which the energy usage finds its link to poverty is multidimensional. Of the most pronounced ones include the type of technology used to convert the raw wood and other biomass into consumable energy. These technologies are characterized by both inefficiency and low qualities [DFID, 2002]. Different sources of energy are categorized in different levels in the 'energy ladder' based on the level of their corresponding efficiency[1]. Based on this ranking, biomass is the lowest level of energy efficiency ladder; charcoal and kerosene are better while electricity and liquefied petroleum gas (LPG) are grouped at the best. The efficiency of stoves using fuelwood, kerosene and gas are estimated to be 15, 20 and 65 percent respectively [Reddy, 2000]. The traditional fuelwood - stove is the most inefficient means of cooking. This implies that first; the system

[1] Efficiency is measured as a fraction of energy released from the carrier of each system.

demands more fuelwood quantities as input to meet the minimum energy. As such, it puts additional demand for more fuelwood. Household members are then obliged to spend substantial amount of their time in fuelwood collection that could have been used for agricultural production or other income generating activities. Second, the system of converting fuelwood to energy using the traditional stove is too inefficient - much of fuelwood is not completely burnt in the stove. As a result, the stove gives off smoke, which also contains health-damaging pollutants [World Bank, 1996; Roger, 1996].

The state of poverty affects the ability of people to take active actions and improving the energy consumption pattern that could benefit their environment. For instance, modern stoves help to increase energy efficiency, thereby reducing the amount of wood and other biomass required as inputs to generate the same unit of energy. However, as Roger (1996) noted, absence of assets, limited access to credit, and low education (or illiteracy) are in the list of factors that deterred the poor from taking such advantages.

1.2 Statement of the Problem

For over 90 percent of the total energy consumption in Ethiopia, and about 99 percent of the rural households, energy consumption is derived from biomass [Alemu, 1999]. The long-standing reliance on biomass gathered from commons and forest is considered as one of the reasons for environmental degradation in the country. This degradation could be explained by various factors, one of which is deforestation. The country's land covered by forest at the beginning of the century that was estimated about 40 percent has dramatically shrunk to less than 3 percent [Alemu, 1999; World Bank, 1984]. The fuelwood production of the country from forests and commons could have caused the deforestation problem. According to the African Development Bank report (ADB, 2002/03), the annual fuelwood production (from both coniferous and non-coniferous), which was about 27.5 million m^3 in the early 1970s to 1974, has increased to 46 million m^3 in 1999.

Deforestation, in its turn, could have exerted an impact on declining agricultural productivity. According to some estimates, about 20 tones soil per ha. per year is eroded from Ethiopian highlands and nearly 1 percent of its best soil is lost [Munasinghe and Meier, 1993]. Needless to say, agriculture is the mainstay of the economy, which contributes the largest share to GDP, employment, and export earnings of the country. The sector's productivity has, however, been threatened by war, loss of soil fertility, recurrent drought, poor farming system of which environment associated problems may be considered as the major constraints.

The inability of the agricultural sector to respond to the increasing food demand of the population - growing, on average, at a rate of 2.9 percent per annum - is making poverty stand as the most fundamental reality of the country. According to World Bank Report (2003), based on the 1999-2000 surveys, more than 44 percent of the population is below the national poverty line with an upward bias to the rural population.

Although the extent to which collection and consumption of fuelwood from forests and commons does contribute to the above trend is not a clear matter, consequences of forest and commons degradation and gathering of fuelwood from this scarce supplies are troublesome for many rural households.

There are other alternatives of domestic fuels that are comparatively available to rural people, and do not cause forest and commons degradation. These are crop residues, animal dung and wood from trees on own farm. Therefore, switching households from collection of commons and forest fuelwood to these alternative sources can reduce forest degradation.

However, these alternative sources of rural energy are not accessible free of costs. They may have substantial financial costs as well as opportunity costs. The private cost structure of rural domestic fuel sources can be financial cost as well as opportunity cost in terms of resource forgone (including own time). In this regard, collection of fuelwood from commons and forests as well as collection of the alternative fuels from own source entails costs. The cost structure faced by households however differs for each fuel type. Collection of fuelwood from commons and forests does not have financial costs. But, it has a potentially large opportunity cost in terms of collection labour time. The opportunity costs for the private sources of rural energy could be the foregone use of the scarce agriculture land that is required to grow trees for fuel. The opportunity costs of burning animal dung and crop residues for domestic fuel could be their alternative uses as manure and animal fodder.

Generally speaking, and in response to fuelwood scarcity of the country, earlier programs were aimed at supplying the 'need gap' through forestry program [Alemu, 1999]. However, planting of new trees through afforestation program is insufficient for future needs and to improve the well-being of the users. In this vein Heltberg et al. (1998) stated that fuelwood collection is subject to the physical scarcity as well as economic scarcity. Physical scarcity of fuelwood is related to the stock and density of forest. Economic scarcity is, however, household specific and depends on physical scarcity, household endowments, fuelwood market, natural resource management and agricultural production therefore it cannot be analyzed in isolation.

Basically lack of finance (assets), poor infrastructure, absence of off-farm employment, cost and availability of improved stoves affect fuel consumption pattern of rural households. In all, it turns out to be apparent, thus, that the situation is far more demanding, hinting at the need to analyze rural fuel collection comprehensively.

This study poses the following questions: How do households respond to fuelwood scarcity? Do they react by substituting between fuels and adopting fuel saving technologies?

1.3 Objectives and Significance of the Study

The objective of the study is to analyze the presence of fuel substitution and to examine the institutional factors influencing behavior of fuel consumption in the study area. To this effect, it deals with the relationship of fuelwood production from commons and forest, and consumption of private energy. It specifically deals with:

a) Determining factors which influence fuelwood collection from commons and forest,

b) Determining factors which influence production of private energy (private energy is here defined as the collection or use of wood, dung, crop residues and for domestic fuel that are collected from private sources), and

c) Assessing whether the two fuel types (fuelwood from commons and private energy) are substitutes or complements,

Findings of the study may help for policy intervention in rehabilitating the environment and reducing poverty.

1.4 Organization of the Study

The rest of the paper is organized as follows. Chapter two provides a literature review where relevant theoretical and empirical work is discussed. Chapter three discusses the methodology and model specification issues, where non-separable version of agricultural household model is developed for the thesis. This is followed by a brief discussion on the empirical strategy in chapter four. In chapter five data description and estimation results are presented. Chapter six is devoted to conclusion and policy implications.

2. LITERATURE REVIEW

2.1. Theoretical Survey

Fuelwood, as dominant source of energy, was used in both developed and developing countries until the middle of nineteen century. In developed countries, however, it has steadily been replaced by other efficient and convenient source of energy owing to their economic development process. Especially after few decades of twentieth century, fuelwood has speedily lost its key place in the energy sector – even for rural households of developed countries. On the contrary, developing countries were much less able to afford efficient and convenient alternative source of energy. Fuelwood has therefore remained as vital part of life in many developing countries [Arnold et al., 2003]. Owing to this vitality, and its far-reaching consequences, it has long been since approached whenever the need arose to address its unfavourable implications, which has mainly been economic.

2.1.1. Fuelwood Gap Model

Attention has begun to fuelwood issues following the oil price shocks of 1973-74, where millions seemed to be facing difficulties in getting enough fuelwood. Early literature on the subject attributed the 'fuelwood crises' to the huge scale consumption of fuelwood with a resultant massive deforestation in developing countries [Mearns and Leach, 1989].

An influential early work on the issue by Eckholm (1975) noted that more than one-third of the world population was struggling every day to find their daily fuelwood requirement from the increasing scarce resources. He referred the situation as 'the other energy crisis' and, recommended a more large-scale tree plantation than what it would have ever been planned before [Arnold et al., 2003].

The earlier concern of fuelwood scarcity and its negative socio-economic consequences on the livelihood of rural poor are basically based on the following summarized postulates. First, increasing difficulty in obtaining fuelwood forces people to go a long distance for collection, increasing the burden and reducing the availability of labour time that could have been allocated in other activities. Second, as a response to fuelwood shortage people would start to use crop residues and animal dung for fuel at the expense of their alternative use (livestock feeds and fertilizer). Removal of these resources from the soil nutrient could reduce agricultural productivity. Third, these 'inferior' quality fuels can damage the health of users. Fourth, the amount of cooked food may be reduced thereby adversely affecting nutrition and health status. Finally, people could be compelled to spend their scarce income on purchasing fuels [Katerere, 1988; Arnold et al., 2003]

In response to such conception of the situation, the following four main strategies were identified to mitigate fuelwood scarcity and its associated multi-dimensional problems:

- Substituting other source of energy (such as kerosene, LPG, and electricity) to the scarce resource i.e. fuelwood.
- Promoting improved stoves that could burn fuelwood more efficiently.
- Improving existing fuelwood production practice through better management of the resource.
- Increasing the fuelwood stock through plantation and forestry programs.

These strategies were generally advocated as having the effect of both increasing the supply of fuelwood and decreasing the demand for fuelwood. Due to the exponential growth of population and its effect on fuelwood demand, most attention was given to the last strategy, though the first three were also seen to have significant contribution in addressing the problem (Arnold et. al, 2003). Essentially, thus, 'fuelwood gap model' was discovered and it quickly began to dominate almost every attempt that would be needed to lessen the problem.

In practice, the model generally boils down on measuring the scale of the fuelwood gap by comparing the present and future fuelwood demand with the standing trees and their annual growth rates. The model came up with a frequent result that consumption of fuelwood greatly exceeded the annual growth of the resources in main parts of the developing countries[2].

Essentially, the fuelwood gap model adopted by FAO (Broadhead et al., 2001) rests on the perceived concern that an increasing physical scarcity of fuelwood imposes significant costs on collectors. By estimating the gap between fuelwood demand and its stock, efforts were hence targeted at increasing the wood stock through afforestation programs.

Consequently, to bring this into effect all policy efforts and interventions were targeted at augmenting the stock. Specifically, rural development strategies of developing countries had centered on the provision of fuelwood supply. Dozens of afforestation programs were then launched in many developing countries to cope up with the rapidly widening 'fuelwood gap'.

Notwithstanding its popularity, the gap model analysis has been brought into question due mainly to its approach and the underlying premises. As Mearns and Leach (1989) pointed out, the earlier fuelwood gap model and its afforestation programs mainly depend on aggregate perspective. As a result, it failed to easily understand that fuelwood problems are areas specific, which require specific intervention. In the same way, Bhattarai (2001) stated in

[2] For a detail discussion on the model and estimates of the gap for countries, see Mearns and Leach (1989).

a zone with abundant supplies, local scarcities of fuelwood could be observed due to limited or no access to the stock and uneven distribution of the resources.

Moreover, in estimating the gap between demand and supply of the stock, consumption was assumed to be increasing as population rises -even to the situation where supply approaches to the vanishing level. However, Mearns and Leach (1989) argue that consumption would be unlikely to increase constantly under a condition where scarcity is high, because people could develop new strategies in response to scarcity.

Similarly, Dewees (1989) pointed out that much of the conventional analysis failed to understand the difference between the physical and economic measures of fuelwood scarcity. The fact that people are unable to get, as much fuelwood as they were before does not necessarily means that there is physically less of it. He argues that if labour is scarce, people could face problem of getting enough fuelwood even if the stock is abundant. Such factors as, out migration to off-farm work could be an important reason to affect the availability of labour time and thereby affecting fuelwood collection.

In a more advanced way of elaboration, Mearns and Leach (1989) argue that without relating physical scarcity of fuelwood to the human dimension, interventions that endeavor to deal with rural fuelwood problem through only supply side approaches, are less likely to succeed. To mention a case, say, increasing a physical scarcity can impose considerable costs on users. One should have to ask, rather, whether these costs are the result of fuelwood scarcity *per se* or more fundamental human dimensions such as; shortage of labour, land endowments, social constraints on access to forest and cultural practices, which are both complex and dynamic.

In light of such complexity, Broadhead et al., (2001) also states that population is not the only variable related to fuelwood consumption problem. If at all projection of fuelwood consumption is necessary, they highlighted other variables that influence consumption such as income, location of consumers, fuelwood supply, the cost and availability of alternative fuels, climate, culture, tradition and household size to be reflected in the model.

In line to the above argument, Cooke et al. (2001) also put forward their critique to the conventional wisdom that scarcity has often been defined in terms of physical magnitude. In early times, physical scarcity was believed to be high if stocks of tree are smaller, forests are further away, or the available fuelwood is of poorer quality. However, according to these writers, this is not a complete definition of scarcity for purposes of household choice. Households make choices about resource allocation if and only if the resources are economically scarce. It is the economic scarcity that derives human choices. In effect, they tend to commend that one must distinguish between physical scarcity and economic scarcity of a good, in which both may not always go in tandem. This is to mean that, in line to Dewees's (1989) idea, economic scarcity of fuelwood may exist in an area with relatively plentiful of physical stocks of wood if labour is hardly available. Conversely, a smaller forest stock in a community may not be related at all to higher economic scarcity of fuelwood in that community if labour is abundant.

Earlier interventions did not take into account the importance of institutional, market and policy failures in fuelwood scarcity. It is often believed that increasing fuelwood prices give better incentives to farmers to increase the supply and sustainability of fuelwood production with a secure income to invest in land management to reduce environmental degradation. However, malfunctioning of fuelwood markets and policies failures such as subsidizing of fuelwood supplies from government forests or fuel subsidies for urban people keep fuelwood prices artificially low. Thus, the combined effects of market and policy failures discourage the rural people to invest in regeneration and management [Arnold et al., 2003; Barbier, 1988]. Moreover, absence of secure property rights discourages the rural people from taking actions of conserving and even increasing the production of increasingly valuable resources that make them better off. Field (1997) states that 'most of the forested land was not owned by individuals or small groups, but was essentially an open-access resource.... A resource of this type often will be overexploited' [Field, 1997: 415].

As stated above, one of the postulated concerns of the earlier belief was that burning of crop residues and dung was taken as a signal of fuelwood shortage, and such practice is strongly believed to result in depriving the people of the benefits of alternative use. However, other arguments put into question the validity of the above analysis. The use of dung and agricultural residues is not necessarily as bad as it was assumed earlier, because making use of manure is not always an alternative. Dewees (1989) argues that the reason why people use these biomass as fuel is because they proved the benefits obtained from soil fertility through applying these resources into farm is less than the cost of their labour time devoted in fuelwood collection. If this argument holds true, the burning of dung and crop residues does not sidetrack rural people from higher welfare. The problems associated with lower quality of these biomass fuels (compared to fuelwood) are likely to be compensated by their lower cost and ease of access [Arnold et al., 2003].

In summary, it becomes increasingly evident that although there could often be a need for plantation to provide fuelwood supply, the gap model and its underlying premises are seriously challenged. The forestry programs launched in many parts of the developing countries just to satisfy rural fuelwood needs were likely to be limited. Moreover, it is sharply argued that fuelwood scarcity is most effectively addressed by the rural households choosing from the array of options, available to them [Arnold et al, 2003]. Consequently, this leads to the validity of inter-fuel substitution, which is synthesized in the energy ladder hypothesis.

2.1.2. The Energy Ladder Hypothesis and Fuel Choice Decision of Households

The most comprehensive hypothesis regarding energy use pattern of households focuses on the concept of 'energy ladder' [Hosier and Dowd, 1988; Arnold et al., 2003]. The energy ladder depicts various combinations of fuels used by a household at its different stage of development. With movements up the ladder, fuel mixes are generally considered as clean and efficient. This is also directly correlated with income growth, bringing about an increased use of modern fuels and less use of biomass [Israel, 2002]. The basic assumption of energy ladder is that a household is faced with a range of different energy supply choices, which can be classified in order of increasing technological sophistication.

Households use fuel for variety of activities, including cooking, water heating, lighting, and space heating. The order of different fuel types on the energy ladder can vary according to this end use. For cooking Munasinghe and Meier (1993), for example, arranged the range of different energy ladder as follows:

1) Dung and crop residues (which are inferior quality biomass fuels, and grouped at the bottom of the ladder);
2) Fuelwood and charcoal (relatively higher quality biomass fuels and placed in the next step);
3) Kerosene;

4) Liquidified petroleum gas (LPG); and, finally

5) Natural gas and electricity[3].

As the economic status of a household rises, reduced use of lower quality fuel type and switch to consumption of relatively higher quality ones occurs. As a result, the household is said to move up in the energy ladder. If, on the other hand, the economic status of household declines, then the household is expected to consume a relative inferior quality fuel. In this regard, Hosier and Dowd (1988) point out that energy ladder acts as a stylized extension of the economic theory of a consumer. That is, as a household increases its income, it makes a decision not only to consume more of the same good, but switches towards consuming other goods of higher quality.

An important aspect of the issue concerning developing countries is how rural households are capable to make fuel substitution along the energy ladder. The economic environment of most rural areas is so constrained that households are faced with a limited array of energy supply. In this connection, French (1985) as in Hosier and Dowd (1988) argues that rural households would continue to depend on fuelwood and their decision-making is, thus, the process of selecting from an opportunity set with a single feasible alternative.

Such an idea led much of the earlier policy efforts undertaken to have focused on rural afforestation and ignores any possibilities of inter-fuel substitution. From a policy perspective, there has appeared to be no way to encourage (Hosier and Dowd, 1988) households to move away from traditional carrier to commercial energy or cleaner biomass.

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[3] For lighting, Leach (1989) sets up the ladder as follows: 1) candle; 2) low efficient kerosene lamp; 3) high efficiency kerosene lamp; and, 4) electricity [Munasinghe and Meier, 1993].

Despite the above negations to the presence of choices in the decision-making of household fuel usage, other authors have suggested that decision-making does occur. Hosier (1985) asserts that rural households take their decision process in two stages: first, they decide which fuel to use, followed by how much of each fuel to use. He notes that resource endowment of households with higher economic status or those who are more integrated to the monetized economy face greater range of fuel options.

Vermeulen (2001) also states that when the preferred type of fuelwood is scarce, households switch first to less favored types and then to non-wood biomass fuels such as crop residues and dung. Arnold et al. (2003) supports the existence of decision making in households fuel consumption. And he elaborates, fuel consumption decision of a household depending more on how its characteristics (such as family size and compositions, taste, opportunity cost relating to time) interact with external factors (such as prices, forest cover, distance to forest and urbanization) and situations than just its income and prices only. Cooke et al., (2001) puts this contention as:

> 'The literature [...] suggests that when the relative prices of different fuels change, households do substitute one fuel for another at least to some extent, whether by using different types of fuels or by using fuelwood collected from different sources. Rural households with land often switch to biomass fuels produced on their own property, and appear to grow trees or bushes for fuelwood in cases where fuelwood scarcity is high enough and alternative fuel substitution too expensive.' [Cooke et al., 2001: 47].

In all, the idea that rural households could make inter-fuel decisions more or less seems to be valid. What is required to facilitate this is decision-making process creating conditions that allow bringing about solutions that households can implement themselves [Arnold et al., 2003].

2.1.3. Fuelwood Scarcity and the Need for Intervention

Whether scarcity of fuelwood is a problem that warrants policy intervention or not depends on whether it inflicts such adverse welfare effects as reducing nutrition or adverse distributional effects (further impoverishment) of the poorest households [Cooke et al., 2001]. Reddy (2000) raised a number of factors that influence fuel choice of rural people. He states that whether the fuel type is gathered or bought, and whether the stove is improved or not, depend on the degree to which the rural economy is subsistence agriculture and/or raising livestock. And, the extent to which rural economy is monetized can affect fuel choice (since wage payment, whether it is in cash or in kind can affect the choice).

Poor people make rational decisions within their institutional set ups about their labour choices and factors that affect their welfare status from the available range of choices [Shyamsundar, 2002]. However, these people tend to live in places, which are ecologically more vulnerable (Roger, 1996) and likely to face a poor set of options (Swanson, 1996). Their limited resource base and locational disadvantage (ESCAP, 2003) dictate to earn their means of livelihood from natural resources. And, in fact, more often than not, the deterioration of these resources turns out to affect the poor disproportionately.

In regard to coping up with fuelwood scarcity of the rural people, different strategies have been documented in the literature. One such strategy is plantation of trees on own land. The problem is, however, that those who are particularly very poor and landless households are less likely or unable to grow trees. According to Roger (1996), the condition of poverty forces households to have high discount rate and a relatively short planning horizon. This means short-term investments are favored over long-term investments. This may arise from the uncertainty of poor people about their future survival and work capacity. While growing trees

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benefit the poor when fuelwood scarcity is high enough, such gains only happens five and more year far into future. This may discourage them from taking such action. Roger (1996) further adds, the problem may also be compounded if the poor are uncertain over future tenure system.

In some circumstances, poor households could switch to the use of dung and crop residues in response to fuelwood scarcity. Nevertheless, these alternative biomass fuels are conditional on agricultural performance [Vermeulen, 2001]. As the subsistence agriculture of the poor frequently registers poor functioning, the possibility of switching to these biomasses is limited to some extent. Vermeulen (2001) asserts that at time of drought where agricultural production fails, food deficit of the poor may be aggravated by sharp fuel scarcity.

In essence, poor households are likely to be the hardest hit by shortage of fuelwood, because they continue to gather fuelwood from increasingly distant and degraded open access [Cooke et al., 2001; Arnold et al., 2003]. In a similar issue, Dasgupta (2003) states that the poorest ones lack possibilities of substitution: whether or not a substitute for a particular resource is neither a matter of technology nor that of a mere taste. Continuing the argument, he states that 'often they can not move and are thus caught in a trap' [Dasgupta, 2003: 10]. Therefore, the decision-making of the poor seems to be the process of selecting from the opportunity set having a single feasible alternative.

From a slightly different perspective on impact of increasing fuelwood scarcity, stated in DFID (2000) the poor spend more time for energy services than those who are better off. The cost of fuelwood collection in cash terms is minimal because it is essentially gathered from commons free of charge. The cost of collection is, however, very expensive in terms of labour time that it takes. This labour cost in terms of household's time rises, as fuelwood becomes scarce. Of course, spending more time in fuelwood collection has little impact on other activities of a household as far as labour is abundant [Dewees, 1989]. However, Vermeulen (2001) contends that for many households, labour is not as such an abundant resource. As a result, households are forced to allocate more time for fuelwood collection and, hence, less time is left for agricultural, home and other income generating activities.

In the final analysis, the types and costs of energy result in a negative effect on resources and well-being of households. For, given their energy consumption pattern discussed thus far, Reddy (2000) strongly asserts, the poor are less likely to save income or accumulate wealth because they pay more for daily energy requirement. The combined effect of these will be exacerbating their poverty, which, in turn, makes the households unable to invest in more efficient fuels and appliances.

Further, poor households have, more or less, limited options of technologies to convert the raw wood and other biomasses into consumable energy. These technologies are characterized by both inefficient and low quality standards [DFID, 2000]. The traditional fuelwood stove is evidently the most inefficient means of cooking. It demands more fuelwood quantities to meet the minimum energy, putting additional demand for fuelwood. The implication is, household members are obliged to spend substantial amount of time to collect fuelwood thereby reducing, once again, the amount of time available for agricultural production, other income generating activities (Roger, 1996) and/or child schooling.

The implication is, therefore, that sustainable rural fuel development calls for legal and institutional reforms including land, tree tenure issues, production, transportation and fuelwood trade (market), technology transfer and dissemination, incentives and human resources [Bhattarai, 2001]. It is the existing institutional arrangements, harboring the culprits that are far more important while addressing environmental benign energy.

2.2. Empirical Evidence

There are some empirical studies that focused on the determinants of fuelwood demand and the substitution of different energy sources, and the links between fuelwood collection and forest degradation in developing countries. Findings of this set of empirical work are organized against the major variables.

The effect of own price

Hyde and Kohlin (2000) reviewed about 10 empirical studies of rural fuelwood demand and found that fuelwood demand is inversely related to its own price implying that demand is price sensitive. Regarding the elasticities, however, they reported that for the majority of the studies, range of the magnitude falls below one in absolute value. Only in one study they did observe own price elasticity is greater than one in absolute value. It can be inferred from the results that rural fuelwood is generally price inelastic. That is to say fuelwood demand of rural households is not very responsive to change in own price. As a result, households reduce their fuelwood consumption by less than one percent for every one-percentage rise of own price.

A study by Heltberg, Arndt and Sekhar (1998) also deals with rural fuelwood collection from forest and private sources. They used the non-separable agricultural household model and applied it to data on 180 households obtained from India's Rajasthan. In the study, collection time measured in terms of hour per kg of fuelwood collected was used as proxy for fuelwood prices. Their econometric results indicate that rural fuelwood collection is inversely related to price (collection time). For a ten-percent increase in price (the time it takes to collect one kg of fuelwood) does only induce to reduce the collection by one percent meaning collection is sensitive to price but inelastic. Fuelwood demand is inelastic means, household expenditure on fuelwood increases as it becomes expensive. This suggests that households are, therefore, responding to fuelwood scarcity by increasing labour input to collection than by reducing consumption or by switching to other fuels.

There are also few household level studies made in Ethiopia. A study by Alemu (1999) assesses whether fuelwood and dung are substitutes and also estimates the price and income elasticities. He estimated the non-separable agricultural household model, using data from a sample survey of 419 rural households in Ethiopia. He employed the generalized Tobit model to check whether selectivity bias problems exist or not. He reported results of Ordinary Least Square (OLS) estimates for those regressions, which did not entail selectivity problem. While results of generalized Tobit model, and estimated by Maximum Likelihood, were reported for the regressions that have selectivity bias problem.

Since price of fuelwood was endogenous in the demand equation, as captured by the marginal product of labour (derived from the fuelwood collection) multiplied by the amount of time spent in collection, instrumental variable estimation was employed. He finds that price elasticity of fuelwood with a value of -0.4, indicating the response of households is not very responsive to fuelwood price.

The effect of cross-price (Substitution between fuels)

Some studies on rural energy consumption have estimated and analyzed the cross-price elasticities with respect to alternative fuels that are available to rural households. Elasticities obtained from the estimate signal how households switch to other fuel types, in response to changes in the relative price of alternative fuels.

The cross-price elasticity in rural area of many developing countries is generally aimed at addressing the issue of whether fuelwood and dung (including crop residues) are substitutes or complements. Many of these studies came up with mixed results. For instance, Amacher et al. (1993) in Cooke et al. (2001) conducted a study with household data from two adjacent districts of Nepal. They found out that different decision - behaviour of households in the study areas. And, actually, fuelwood and crop residues seem to be substitutes in one of the districts, though they were complements in the other adjacent district.

Such a mixed result is also observed in Ethiopia. Study reports on whether fuelwood and dung, which are the most important source of energy in the rural Ethiopia, are substitutes or not seem to be inconsistent. An early study by the World Bank (1984) alludes that fuelwood and dung are substitutes, where as for the worsening fuelwood scarcity people are increasingly responding by substituting dung for fuel. It stated that '[t]o compensate for the worsening firewood scarcity, growing amount of natural fertilizers in dung and crop residues are being diverted to household fireplaces, reducing crop yields by more than one million tones of grain in a year' [World Bank, 1984: 3]. The study, hence, suggested that 6 million hectares be planted in three decades to arrest the deforestation and fuelwood problem.

Another nation-wide survey (ENEC, 1986), however, claims that the use of dung and agricultural residues being used as cooking fuel does not mean that people are switching to these biomasses in response to scarcity of fuelwood. Instead, the study argues, the use of these biomaterial fuels is because of the quality of energy (high flames) they provide. People's response to the fuelwood scarcity in this case is reducing the amount of fuelwood usage through economical use of the domestic fuel or through technological improvement (i.e. adoption of improved stove that uses less amount of biomasses as input to release the same unit of energy) [Alemu, 1999].

Asmerom (1991) also examined the cross price effect of fuelwood demand and the other bio fuels - dung and crop residues - in his estimates of rural fuel demand. He reported that demand for dung and crop residues appears to be directly related to the fuelwood price. This shows that the two fuel types are substitutes rather than complements, though; the value of the elasticity was low [Alemu, 1999; Alemu and Tekie, 2001].

Alemu (1999) tried to see whether fuelwood and dung are substitutes or not. From estimates of demand function for both fuel types, he finds the cross price elasticities are either - negative and significant, or positive and insignificant. To make this clear the shadow price of dung has a significant negative impact on fuelwood demand. The shadow price of fuelwood, on the other hand, has a positive effect on the demand for dung but insignificant. Thus, substitutability of the two fuel types is not evidenced. Instead, according to the result, they are either complements or independent.

To sum, the above studies show that fuel substitution behaviour of rural households seems to vary from one place to another. This supports the argument that fuelwood scarcity needs local specific intervention.

The impact of income

Household income is also another important variable to consider in fuelwood demand. Income is measured differently in those studies that have included the variable in their estimation.

Israel (2002) studies the effect of income growth on fuelwood and how females' earned income affects fuel choice, using 6892 households from Bolivia. He used per capita household expenditure as a measure of available household resources to look at its effect on fuelwood demand. Heckman's selection approach is employed in the study. He finds that income has a positive effect on fuelwood demand with an elasticity value of 0.88, which is relatively inelastic. This demonstrates, as spending power increases, households incline to raise their fuelwood use.

For the case of rural Ethiopia, Asmerom (1991) finds that demand for dung and crop residues are inversely associated with income. This explains that dung and crop residues are likely to be inferior goods that are consumed by low-income households.

To examine the effect of income on biomass fuel, Alemu (1999) treated income in two different variables. He decomposed it into labour and non-labour income in order to capture differences in labour availability returns to labour in activities other than fuelwood collection. His results show that both type of income appeared to have both positive and negative impacts on demand for fuelwood and dung respectively implying the former is a normal good and while the latter is an inferior. That is, households with high income tend to use more of fuelwood and less of dung. Results of the implied elasticities range between -0.17 and 0.056, depicting inelasticity with respect to income.

Lessons that can be drawn from the above results are that the impact of income on fuelwood use seems to be low. It is also observed that dung and crop residues appear to be inferior goods, whereby their consumption decreases as income rises.

The impact of private tree

Different studies show that as the community resources becoming increasingly scarce, households switch to their private trees for fuelwood collection. Heltberg, Arndt, and Sekhar (1998) examine fuelwood collection from private sources and forest. They report that fuelwood collection (including dung and crop residues) from trees grown on private field increases as stock of the resource declines in the Rajasthan forest. Further, they found that as the number of private trees increases the amount of fuelwood collected from private source increase, while the amount collected from forest decreases by reducing the labour time spent on the latter.

Cooke (2000) also observed a similar result for Nepal. That is, if the stock in the forest is high, then households tend to collect more from forest and less from the private trees [Cooke et al., (2001)].

Alemu (1999) also found, growing (having) private trees have a significantly positive influence on households' collection of fuelwood (from all sources) in rural Ethiopia.

In short, results of the studies support that fuelwood from forest and private sources seem to be substitutable for rural household.

Labour allocation

How a household makes division of labour among its members and how each allocates its labour is another appealing concern that draws attention of certain studies. The forestry and community development programs conclude fuelwood collection as a female task. However there is mounting evidence that fuelwood collection is not a female task only. In their review of studies on the subject of gender division of labour in fuelwood collection, Cooke et al. (2001) found, household labour allocation to have seemed to be consistent with economic rewards against the usual supposition that considered women as principal collectors. That is, in situations where there is high return to male collection, men may collect more fuelwood than women.

Heltberg et al., (1998) also finds both the number of adult men, women and children have a significant and positive effect on fuelwood collection from forests in rural India. A similar study by Linder-Rahr (1999) in rural Vietnam also reports both male and female are significantly involved in the fuelwood gathering from open access. He mentioned that women's fear of being attacked during the walk to open access might act as one possible reason for males' engagement in the collection.

Alemu (1999) also made an effort on the issue for the case of Ethiopia. In his analysis, the involvement of both male and female appears to be significant in the total fuelwood collection (collection of woody biomass from both private and commons). In addition, females are found to be significantly influencing fuelwood gathering from commons but not males. From the frequent statistically significance of females especially for the collection from commons, he remarks that females may be more important in fuel collection.

Household endowment

The number of livestock and size of land holding are other most important variables that are associated with fuelwood collection. Heltberg et al. (1998) found that the size of land holding has a significant positive effect on fuelwood collection from private sources. It has also a considerable effect on reducing the amount of fuelwood collected from forest. On the contrary, Cooke (2000) finds that land size influences fuelwood collection from neither private sources nor that of commons [Cooke et al., 2001].

Heltberg et al., (1998) report that the impact of livestock ownership on collection of fuelwood from forest, however, appears to be insignificant. Alemu (1999) included the number of cattle in the production function and demand function for both fuelwood and dung, and finds positive signs and the estimated parameters are statistically significant in all cases.

Impacts of fuelwood scarcity in rural household welfare

The empirical studies presented thus far, evidenced that households actively respond to increasing scarcity of fuelwood by allocating more time to collection, or by putting more resources into private production of fuelwood than to rely on market purchases. The next important question is, hence: do such adjustments to the increasing fuelwood scarcity cause reduction in household welfare status that warrants intervention?

One potential concern of the fuelwood scarcity is its impact on bringing down household's nutrition and adverse health effect. Cooke et al., (2001) summarized results of some empirical studies (Kumar and Hotchkiss, 1986; Cooke, 1995; Amacher et al., 2001; Parikh and Vijalaxmi, 2000) that dealt with fuelwood scarcity and welfare issue. Accordingly, Kumar and Hotchkiss find that fuelwood scarcity reduces household welfare through decreasing time spent on cooking, thereby depressing their nutrition. Moreover, those children engaged in fuelwood collection and other joint activities are found to be lower height- for- age -measurement in Nepal. From another dimension on the same issue, Cooke also finds a comparable result for the Nepali household that total consumption per capita of household declines as the fuelwood shadow price rises. This reflects fuelwood scarcity brings about reduction of nutrition, for which food constitutes the major share of the total expenditure. The result of Parikh and Vijalaxmi indicates the prevalence ratio of respiratory disease and eye irritation for biomass fuel users compared to LPG users is higher by a factor 1.6 and 1.4 respectively for Tamilnadu rural people [Cooke et al., 2001].

A recent empirical work on health effects of biomass energy is the one by Wickramasinghe (2003). The study is more descriptive based on the responses of the 720 households from Sir-Lanka. Self- perceived problems are taken as testimony in the study. Household members, on average, spend 3 to 7 hours in fuelwood collection per trip. The study reports that impact of biomass-based energy on health is distributed disproportionately among members of the community. Women seriously suffered due to their efforts in ensuring the energy demanded by the household. Two years morbidity records associated with the carrying and procuring of biomass fuels in the survey area show gender-differentiation.

We find only one study that examines the impact of fuelwood scarcity on health in Ethiopia. A study by Amacher et al., (2001) quoted in Cooke et al. (2001) looks at the fuelwood scarcity on health of rural households in Ethiopia's highlands. Their result reveals, as wood becomes increasingly scarce, most households are unable to get sufficient fuelwood for heating as a result of which members are forced to fall ill. The situation becomes more serious when proxied and gauged by the number of sick-days of the family members that hampered the fuelwood collection task.

Improved stove adoption and its role

An intervention aimed at improving the situation of fuelwood scarcity for rural people was encouraging and enabling the adoption of more fuel-efficient stoves. To this end, several programs have been introduced to develop and disseminate of improved stoves since 1980's. Such programs have mixed results. Regarding the coverage, China accounts for about 90 percent of the total improved stoves disseminated in the world in the last 20 years. So far, the number of modern stoves disseminated in Ethiopia is very low. In 1995, for example, while the number of improved stoves disseminated in Ethiopia was 44,000 (23,000 for urban and 22,000 for rural areas), for Kenya the figure was about 780,000 [Goldemberg 2000].

Dissemination of improved stove program in Ethiopia has been launched since 1989. The program has designed about three types of stoves, namely " *Lakech*" (an improved stove for charcoal), "*Mirte*" (an improved stove for biomass), and low cost electric *Mitad*. It has been reported that *Lakech* reduces the amount of charcoal by about 25 percent from the traditional charcoal stove. *Mirte* is also expected to reduce the amount of biomass roughly by 23 percent. As in the case of most of developing countries, the dissemination and promoting efforts are claimed to have lagged behind [Alemu and Tekie 2001].

More importantly, owning an improved stove does not necessarily reduce the amount of fuelwood consumption in many developing countries [Cooke et al. 2001]. A recent household level study of improved stove that we could find is by Heltberg et al. (1998). They have included an indicator for ownership of improved stove in their estimation of fuelwood collection in rural India, to see the effect of the technology in the domestic fuel consumption. Their result, however, shows that ownership of the improved stove does not significantly influence fuelwood collection.

In general, a review on empirical evidence reveled that the program of disseminating improved stoves has failed to its widespread adoption. The main factors, which accounts for this are the mismatch between the need of the rural poor and the assumption of the designers and promoters of improved stoves. The concern of many households is about the speed of cooking whilst stove programs emphasized fuel saving. The program neglected a number of socio-cultural and practical functions. The cost of improved stoves, and lack of assets or limited access to credit are also some of the reasons, which contributed to failure of the program [Gill 1985; Marks 1996].

3. METHODOLOGY AND DATA ISSUES

3.1. Agricultural Household Model for Rural Fuel Supply and Demand

3.1.1. Rationale

Agricultural households are engaged in production, consumption, and labour supply decisions simultaneously [Sadoulet and de Janvry, 1995]. Agricultural households involve in production activities, and sell part of their outputs that exceeds their consumption and purchase when production falls short of their consumption. Similarly, households sell their labour that exceeds their own farm use, and purchase (hire labour) if demand outstrips their supply. In circumstances where households behave as producer, consumer as well as labour supplier, a policy intervention in agriculture sector does not only affect its decision to production, but it also affects its consumption and labour supply decisions. Thus, agricultural household models, which integrate household decisions of production, consumption and labour supply, (Sadoulet and de Janvry, 1995) are designed to capture these relationships in a theoretically consistent fashion [Singh et al., 1986].

Nakajima (1969) in Abdulhamid (1992) stated that the degree of subsistence consumption of own output and family labour use as percentage of total labour employed could be used as criteria to identify household's farming system. In the utmost case of pure subsistence, households consume only what they produce and all labour is family labour. The other extreme case is commercial farm where all produced outputs are sold in the market and all labour is employed labour. The remaining is placed in between the extreme cases [Abdulhamid, 1992].

If prices of all outputs and factors are exogenous, production and consumption decisions are made sequentially (Sadoulet and de Janvry, 1995) with the direction of the decision arrow being from production to consumption. Production decisions are thus, independent of consumption and labour supply decisions. Production and consumption decisions, in this case, are linked one way through income only, which is determined in the production side [Sadoulet and de Janvry, 1995]. Under such condition, changes in the production sector have no implications on labour or consumption prices; consequently, this assumption allows researchers to estimate the production and consumption sectors independently or recursively [Lopez, 1986].

Lopez (1986) states different factors that do not warrant the importance of separable model. He claims that existence of commuting time associated with off-farm work, different preference of households for on-farm and off-farm work, imperfect substitutability between hired and family labour are some of the sources of interdependent utility and profit maximizing decisions. The main source of such interdependence is due to the existence of endogenous shadow price that would become a basic linkage between the production and consumption sectors of the model.

In general, the agricultural household is situated in an environment where a number of market failures appear. The extreme case of market failure is non-existence of market. In such a case where a household is consuming all of its outputs / factors, its production, consumption and labour supply decisions are made simultaneously. Granted, there is a possibility that some type of market could exist for agricultural households. Nevertheless, market failure could still exist when household faces a wide range of price bands between the low price at which it could sell its output or factor and high price at which it could buy that product or factor. As a result, it may be better off choosing self-sufficiency in that output, if their subjective price (defined as the price, which equates its supply and demand) falls inside the band. This implies, if there is market failure, the corresponding output or factor becomes non-tradable and its 'price' is subjective to the household taken as a shadow price [Sadoulet and de Janvry, 1995]. In this case, production and consumption decisions are determined simultaneously and the model appears as non-separable.

3.2 Specification of the Model

In rural Ethiopia, where consumption of commercial energy is very limited, households procure domestic fuel by gathering from forests, commons and private sources. For a large share of households, collection of fuelwood is made by own labour [Alemu and Tekie, 2001]. This implies that rural households are characterized as producers as well as consumers of fuelwood. This joint decision of production and consumption of fuelwood by households suggest the application of agricultural household model, rather than the pure demand model [Singh et al., 1986]

Specifically, as in most developing economies, market for domestic fuel, at worst, does not exist in the rural areas, and is imperfect, at best. Studies by Alemu (1999), and Alemu and Tekie (2001) suggest the imperfection of domestic fuel market in the rural area and that the majority of rural households are not involved in the fuel market. Moreover, even the labour market in these areas is also imperfect. Farm households have limited access to off-farm labour market. Given the foregoing basic features of rural markets, thus, non-separable model could easily capture the realities more closely.

In all, due to existence of dual market imperfections, non-separable agricultural household model is deployed in the study. Once again, the assumption of non-separable theoretical model implies households make decisions on allocating their resources; including energy supply, energy demand, and on-farm and off- farm labour supply simultaneously. Furthermore, households determine their energy collection and consumption by maximizing their utility subject to a shadow price of energy, which varies from one household to another depending on their characteristics [Heltberg et al., 1989].

The model developed below captures the situation of a farm household engaged in on-farm, off-farm and domestic fuel collection activities. It focuses on the choice between collections of commons fuelwood versus private fuel (private energy)[4].

Against the foregoing background the model in this research is constructed as follows[5]: The farm household maximizes its utility (U) function given by;

$$\textbf{max U} = U(X_E, X_O, X_L; D^c) \quad \text{...} \quad \textbf{(1)}$$

where X_E represents consumption of energy; X_O is other commodities which do not require fuel; X_L is leisure consumption of the household; D^c is a vector of household characteristics pertaining to consumption.

Fuel consumption of a household depends on the amount of the fuelwood and private energy consumed and the type of technology it has access to.

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[4] Commons fuelwood refers to collection of fuelwood from commons and forest. Private fuel, on the other hand, involves the use of dung, crop residues and wood for domestic fuel that are collected from private sources. Hereafter commons fuelwood and private fuel (private energy) are cited in the remaining part of the study in reference with the above categorization.

[5] The presentation closely follows the work of Heltberg, Arndt and Sekhar (1998) on rural energy of India. A reference is also made to the study of Alemu (1999).

$$X_E = X_E(X_{FW}, X_{PE}, S) \quad (2)$$

where X_{FW} represents consumption of commons fuelwood, and X_{PE} is consumption of private energy (dung, crop residues and wood from private sources). Motivated by the data set used in this study, other source of energy like kerosene is assumed to be not common in rural area[6], and S stands for technology or ownership of improved stoves.

Production of commons fuelwood, Q_{FW}, is defined as;

$$Q_{FW} = Q_{FW}(L_{FW}; D^{FW}) \quad (3)$$

where L_{FW} is household labor time spent on gathering fuelwood and D^{FW} is a vector of characteristics describing forest stock like distance from homestead to forest that are relevant to fuel production.

Agricultural production function, Q_{AG}, is defined as

$$Q_{AG} = Q_{AG}(L_{AG}, Inp; D^{AG}) \quad (4)$$

where L_{AG} represents farm labour; Inp is the use of residues and dung as farm inputs; and D^{AG} is a vector of endowments related to farm production such as land, livestock and trees which are assumed to be fixed.

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[6] From the total households considered in the survey, the share of kerosene is very minimal and its purpose is mainly for lighting (For detail, see discussion on the description of the survey data in chapter 5).

The household can use dung and crop residues either as farm production inputs or for domestic fuel termed as private fuel (private energy). It is assumed that the amount of these resources (dung and crop residues) available to the household is a certain constant portion of agricultural output, αQ_{AG}.

The supply constraint of private energy denoting as Q_{PE}, is therefore defined as:

$$Q_{PE} = \alpha Q_{AG} - Inp \text{ .... (5)}$$

Budget constraint is defined as

$$P_O X_O = P_{FW} (Q_{FW} - X_{FW}) + P_{AG} Q_{AG} + w L_{OFF} \text{ .... (6)}$$

where P_O, P_{FW}, and P_{AG} represent market prices of other goods, fuelwood, and agricultural goods respectively; $P_{AG} Q_{AG}$ is restricted farm profit (gross of own labour); w and L_{OFF} denote wage rate and labour time spent on off-farm activities respectively.

Time constraint is given by:

$$T = L_{AG} + L_{FW} + L_{OFF} + X_L \text{ .... (7)}$$

Though households are assumed to collect all fuels for themselves, some households may occasionally sell fuelwood. The market condition is therefore expressed as[7]:

$$Q_{FW} - X_{FW} \geq 0 \quad \text{.. (8)}$$

The condition states that a household is net seller if the strict inequality holds; otherwise they are self-sufficient if the equality holds. For simplicity private fuel is assumed to be non-traded. Hence, $Q_{PE} = X_{PE}$.

Other non-negativity constraints are;

$$Q_i \geq 0, \quad i = FW, PE, AG \qquad X_j \geq 0, \quad j = FW, PE, O, L \qquad L_k \geq 0, \quad k = FW, AG, OFF \quad \text{.......................... (9)}$$

After inserting equation (2) into equation 1 for X_E and substituting the production relationships (equation 4 and 5) into the budget constraint (6), the Lagrangian function for the problem could be written as;

$$\begin{aligned} L = {} & U(X_E(X_{FW}, X_{PE}, S), X_O, X_L; D^C) \\ & + \lambda[P_{FW}(Q_{FW} - X_{FW}) + P_{AG}(Q_{AG}(L_{AG}, \alpha Q_{AG} - Q_{PE}; D^{AG}) + wL_{OFF} - P_O X_O] \\ & + \gamma[Q_{FW}(L_{FW}; D^{FW}) - Q_{FW}] \\ & + \phi[T - L_{AG} - L_{OFF} - L_{FW} - X_L] \\ & + \mu[Q_{FW} - X_{FW}] \end{aligned} \quad \text{...... (10)}$$

where λ, γ, ϕ and μ are Lagrangian multipliers attached to budget, fuelwood production, time constraints and market conditions respectively.

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[7] The model can also accommodate households that are net buyers of fuelwood without essentially changing the basic results of the model.

Assuming interior solutions, we have the following first order conditions:

$$\frac{\partial L}{\partial X_{FW}} = \frac{\partial U}{\partial X_E}\frac{\partial X_E}{\partial X_{FW}} = \lambda P_{FW} + \mu \quad \text{.......................................(11)}$$

$$\frac{\partial L}{\partial Q_{FW}} = \lambda P_{FW} + \mu - \gamma = 0 \quad \text{.......................................(12)}$$

$$\frac{\partial L}{\partial L_{FW}} = \gamma \frac{\partial Q_{FW}}{\partial L_{FW}} - \phi = 0 \quad \text{.......................................(13)}$$

$$\frac{\partial L}{\partial X_{PE}} = \frac{\partial U}{\partial X_E}\frac{\partial X_E}{\partial Q_{PE}} = 0 \quad \text{.......................................(14)}$$

$$\frac{\partial L}{\partial Q_{PE}} = \lambda P_{AG}\frac{\partial Q_{AG}}{\partial Inp} = 0 \quad \text{.......................................(15)}$$

$$\frac{\partial L}{\partial X_L} = \frac{\partial U}{\partial X_L} - \phi = 0 \quad \text{.......................................(16)}$$

$$\frac{\partial L}{\partial L_{OFF}} = \lambda w - \phi = 0 \quad \text{.......................................(17)}$$

$$\frac{\partial L}{\partial L_{AG}} = \lambda P_{AG}\frac{\partial Q_{AG}}{\partial L_{AG}} - \phi = 0 \quad \text{.......................................(18)}$$

Rearranging some of the above first order conditions, we obtain the following relationships:

$$\frac{\partial U}{\partial X_E}\frac{\partial X_E}{\partial X_{FW}} = \gamma = \lambda(P_{FW} + \frac{\mu}{\lambda}). \quad \text{.......................................(19)}$$

Equation 19 shows that a household equates the marginal utility of fuelwood consumption to the shadow cost of fuelwood collection (γ). But this reservation price is different from the market price. Depending on the sign of $\frac{\mu}{\lambda}$, the reservation price could be generally equal to, smaller or larger than the market price depending on whether the household is self-sufficient in, a net seller or buyer. If the reservation price is equal to the market price, the household will be a net seller. On the other, a household would be self-sufficient if its reservation price exceeds the market price.

$$\frac{\partial U}{\partial X_L} = \gamma \frac{\partial Q_{FW}}{\partial L_{FW}} = \lambda P_{AG} \frac{\partial Q_{AG}}{\partial L_{AG}} = \lambda w \quad \text{.......................(20)}$$

Equation 20 shows that the household collects fuelwood, until the marginal utility of leisure is equal to the marginal value product of labour in fuelwood collection, and these, in turn, are equalized to the point where the marginal value product of labour in agriculture and the wage rate are equal.

The model explains that a household's decision to be engaged in fuelwood collection or not is determined by the opportunity cost of its labor time in the on-farm and off-farm activities. If the wage rises, the household withdraws its labour from fuelwood collection to off farm activities[8]. The existence (absence) of off-farm activities has, therefore, a role in preserving (degrading) the forest resource.

From equations 13 and 14 of first order conditions, we can get the following relationship:

$$\frac{\partial U}{\partial X_E} \frac{\partial X_E}{\partial Q_{PE}} = \lambda P_{AG} \frac{\partial Q_{AG}}{\partial Inp} \quad \text{....................................... (21)}$$

[8] If labour division among family members is assumed that only women and children collect fuelwood and only adult men face off-farm opportunity, then an increase in wage draws male from farm. Following this female and children labour flows to farm activities at the expense of fuelwood collection.

Equation (21) depicts the household will use dung and crop residues for fuel up to the point where marginal utility of private energy (the left hand side term) equates to their marginal value product when used as farm inputs (the right hand side). This shows that the consumption of private energy is determined by the opportunity cost of dung and crop residues as farm inputs. In the case of private trees, the opportunity cost could be the alternative use of land they occupy.

Finally, the reduced form equations of fuelwood collection, amount of time spent on collecting, and private energy production that can be derived from the first order conditions, are the basis of the empirical work and take the following general form as functions of all the exogenous variables.

$$Q_{FW} = f(D^{c}, D^{FW}, D^{AG}, P_{FW}, w, S, P_{AG}, P_{O}) \quad \textbf{22(a)}$$

$$L_{FW} = f(D^{c}, D^{FW}, D^{AG}, P_{FW}, w, S, P_{AG}, P_{O}) \quad \textbf{22(b)}$$

$$Q_{PE} = f(D^{c}, D^{FW}, D^{AG}, P_{FW}, w, S, P_{AG}, P_{O}) \quad \textbf{22(c)}$$

4. EMPIRICAL SPECIFICATION

4.1. Empirical Specification

4.1.1. Estimation Issues

As discussed above, this study is based on the theoretical framework of non-separable agricultural household model. Its empirical estimation brings a number of issues, which will be discussed each in turn shortly. From the first order conditions i.e., equations (11-18), a number of demand and supply decisions of the household can be solved. These include, demand and supply of fuelwood; labour supply for fuelwood, off-farm, and on-farm; and demand for leisure and other commodities.

To start with, the non-separable model dictates estimation of the full system (all supply and demand functions) simultaneously. The implication is that, collection of, consumption of, and labour supply for fuelwood should be estimated simultaneously. However, as the model can be represented only explicitly by unobservable prices, the estimation task turns out to be very difficult. Consequently, estimating the whole system simultaneously is not commonly practiced [Sadoulet and de Janvry, 1995].

An alternative approach is, hence, estimating the reduced form of production and consumption equations separately: each equation regressed on all exogenous variables pertaining to consumption as well as production behavior of a household. The consumption decision in this case depends on household characteristics related to consumption as well as production. Likewise, unlike the pure producer model[9], the production decisions are also dependent on both characteristics [Sadoulet and de Janvry 1995]. That is, there are variables

[9] In the pure producer model, decisions of production are related only to household production characteristics.

that would not be included in the estimation of market demand, while they will be included in the household model. And, there are variables that would not be included in market supply estimation while they will be included in household supply [Cooke et al., 2001]. At this level, the equations can be estimated independently. In our case estimation is, therefore, confined to the three reduced form equations (22 a-c) that are the primary interests regarding the analysis of fuelwood collection and energy substitution.

In the data set used in our study, some households do not collect fuelwood from commons. Virtually all households can have access to the commons. But only 45 percent of the sample did in fact collect from this source. Regarding the collection of private energy there are many occasions where households own tree, and/or have access to dung and/or crop residues from private sources. Although all households can generate their private fuel from their own sources, only 81 percent did pursue actual collection.

Tobit model accounts for the problem of households with zero collection for a particular fuel type. Its disadvantage, however, is that if the variable increases the probability of selecting into the group (e.g. collection of fuel), it also increases the conditional mean of the variable of interest (e.g. amount of fuel collection). That is, Tobit model rules out some interesting possibilities of certain variables that increase the probability of households to fall into fuel collectors but conditional on being collectors, the amount of fuel collected might decrease with these variables [Wooldridge, 2003]. For this reason, we use a Heckman Selection approach to model for each fuel collection.

To correct sample selection bias that may be appeared while analyzing those involved in the collection, the Heckman selection model involves estimating both a fuel choice probit and quantity of fuel-collected regression, as explained below.

The estimation is based on the following model of fuel collection.

$$\mathbf{z}^* = \gamma\omega + \mu \text{ .... } \mathbf{(23)}$$

where $\mathbf{z}^*$ is vector of unabsorbed propensity to fuel collection, γ is vector of parameters to be estimated and ω is the matrix of covariates. Whether a household chooses to collect fuel can be represented by a binary variable, z = 1, if household collect fuel type, and z = 0 if not.

The selection indicator z is related to the unabsorbed variable such that z = 1 if $\mathbf{z}^* > 0$ and z = 0 if $\mathbf{z}^* \leq 0$, and follows the following probit model.

$$\mathbf{Pr}\ (\mathbf{z} = \mathbf{1} \mid \omega) = \Phi\ (\gamma\omega) \text{ .... } \mathbf{(24)}$$

where $\mathbf{z} = 1$ if a household collect fuel (and $\mathbf{z}^* > 0$)

This selection mechanism is incorporated in the quantity of fuel collected regression model. The following regression model is observed if $\mathbf{z} = 1$

$$\mathbf{Y} = \beta\mathbf{x} + \varepsilon \text{ .... } \mathbf{(25)}$$

where μ and ε bivariate normal $(0, 0, 1, \sigma^2_\varepsilon, \rho)$, **Y** is vector of dependent variables denoting quantity of fuel collected, **x** is matrix of explanatory variables and β is the matrix of parameters to be estimated.

$$E(\mathbf{Y} \mid z = 1) = \boldsymbol{\beta}\mathbf{x} + \rho\sigma_\varepsilon\lambda(\gamma\omega) \quad \text{.......................................(26)}$$

Equation (26) shows that we can run the estimation using only the selected sample (those fuel collectors), provided we included $\lambda(\gamma\omega)$ as an additional regressor, which is obtained from the probit selection equation (24).

Fuelwood markets in the study area, as discussed above are not well functioning and are highly localized. Fuelwood market prices, which vary substantially across households and study sites, are therefore unlikely to be entirely exogenous. More importantly, for the majority of the households that are not involved in the fuelwood trading, market price of fuelwood is irrelevant. Because for the latter group, their collection of fuelwood equals their consumption of it, $Q_{FW} = X_{FW}$, as a result $P_{FW}(Q_{FW} - X_{FW})$ portion of their budget constraint of equation (6) becomes zero. Altogether, market price of fuelwood is unattractive to include in the explanatory variables. Hence, another measure that indicates scarcity of the resource sought for. In effect, and given that fuelwood collection is a labour intensive activity; the opportunity cost of time is commonly used (Alemu, 1999; Cooke et al., 2001) to capture the economic cost. The time collection measured as hour per a kilogram of fuelwood collected is, therefore, used as a proxy for the price of fuelwood collected. It can be interpreted that the longer the time households spend to collect a unit of fuelwood, the higher becomes the cost of collecting a unit of fuelwood from commons, *ceteris paribus*.

The collection time per unit of fuelwood variable is household specific for various reasons, implying it is endogenous. Differences in household composition and resource endowments of households are some of the factors that cause endogeneity. To correct for inconsistency that may be caused by endogeneity of the variable, we apply the following procedures. First, we estimate the probit equation (24) using the exogenous variables, and obtaining $\lambda(\gamma\omega)$ (i.e., the mills inverse ratio). Second, we included the additional regressor, $\lambda(\gamma\omega)$, to regression equations of (26) and estimated by Two Stage Least Squares (TSLS) [Wooldridge, 2003].

Households that entirely depend on private energy (those did not collect fuelwood from commons) do not have collection time of fuelwood, meaning we lack value for price of collection. But, even when a household decided not to collect fuelwood from commons, it faces an opportunity price in this activity. For this reason, omitting observations from the equations, due to missing fuelwood price information, would bias our results. Therefore, assuming these people could have an equal access to collection of fuelwood from commons, we have imputed the village average fuelwood price as a relevant price faced by these households.

Moreover, due to labour market imperfections and lack of data, the market wage rate is substituted by education level of household head to account for labour market opportunity. Agricultural output prices, P_a, and prices of other commodities, P_m, are assumed to be the same for all households. For this reason, both are excluded from the explanatory variables.

4.2. Definition of Variables and their Hypothesized Signs

1. **Collection time per unit of fuelwood.** This variable is included to capture the time cost of fuelwood collection. As collection time of fuelwood increases, households reduce their fuelwood consumption.

2. **Land size holding of a household.** It is included as one of the proxy variables that measure the scarcity of private fuel. As land holding increases, the amount of agricultural residues collected by households also rises. It is, therefore, expected to influence private energy positively.

3. **Number of Cattle ownership.** This is also supposed to seize up the scarcity of private fuel indirectly. As the number of livestock owned by household increases, the availability of dung increases. Hence, its effect on private fuel is positive.

4. **Number of trees.** This also expected to capture the scarcity of private fuel. Having a number of trees in the household's residence or in its agricultural land is expected to induce private fuel consumption while it reduces fuelwood consumption from forest.

In the absence of data on fuelwood and private fuel prices, the scarcity of each fuel type and household's response will be analyzed through the effect of above variables. The response of private fuel collectors to collection time per unit of fuelwood, and the influences of land, cattle and number of trees on fuelwood collection depend on whether the two (i.e., commons fuelwood and private energy) are substitutable or complementary fuel types.

5. **Number of males and females.** These are also separately entered in the regression equations. Both are expected to have a positive influence on the amount of fuelwood collection and quantity of labor supplied for fuelwood collection by increasing energy demand and availability of labor respectively. Their influence on private fuel is undetermined.

6. **Dummy for improved stoves.** (1 = for a household with improved stoves and 0 = for a household without improved stoves): An improved stove is expected to reduce both commons fuelwood and private fuel consumption due to its high efficiency compared to traditional stoves. It also influences the amount of labour supply to fuelwood collection negatively.

7. **Education level of household head.** Education is assumed to widen the opportunity of off-farm work, and affects fuelwood consumption of a household negatively via withdrawing its labour from fuelwood collection to off-farm activities.

8. **Different site dummies**. Site dummies are also included to capture inter-site differences.

5. EMPIRICAL ANALYSIS

5.1. Description of Survey Data

The data for the study is generated from the survey conducted by the department of Economics, Addis Ababa University in 2000. Aimed at studying rural households regarding sustainable land use in the Ethiopia highlands, it provides information on a wide range of socio economic variables from a total of 1515 households in 12 Kebeles[10]. The samples Kebeles are drawn from East Gojam and South Wello. The questionnaire is organized in eight sections: Sections one and two are devoted to information on the basic demographic characteristics and agricultural land use production and consumption of a household respectively; sections three and four are structured for collecting data on, among others, trees and livestock ownership, and income. Sections five and six gather information basically on off-farm income, and remittance; the last two sections (section seven and eight) are about energy - cooking and consumption habits, and preference revelation, respectively.

Using data obtained from the aforesaid sections, important statistical figures including mean, minimum, maximum and standard deviations covered in the sample are computed for the basic variables of the study. After eliminating households with missing data as well as households that do not collect any of the two fuels of interest, estimations are based on 1308 households.

Among the households used in this study, the most commonly used fuels are fuelwood (collected from private trees and commons), dung and crop residues. Kerosene is sometimes

[10] The names of the kebeles are: Amanuel, D. Elias, Kebi, Wolikie, Telmia, and Sekla Debir from East Gojam; and Kete, GodGuadit, Amba Mariam, Yamed, Adis Mender and Chorisa from South Wello.

used in the area mainly for lighting purpose. After converting the energy value of each fuel type into a single unit (i.e. Kilocalorie, kcl, is used in this study), the share of kerosene out of the total energy consumed in the study area is very minimal[11]. A simple computation of the energy consumption of the households used in the analysis shows that biomass fuels (fuelwood, dung and crop residues) consist about 98.6 percent while kerosene only represents 1.4 percent. Because of the different tasks performed by kerosene and its insignificant share, it can be justified to exclude it from the present analysis. The predominantly biomass fuel use in the study area is similar to the national estimates of rural Ethiopia that is, 99 percent [Alemu, 1999].

Table 1. Descriptive statistics of fuel collection in the survey area for the whole sample

Variable name	Mean	S. Error	Min.	Max.
Monthly fuelwood collected from commons and forest (in 000 kcl)	313	510	0	2874
Monthly collection labour time of fuelwood from commons and forest (in hours)	23.7	48.7	0	475
Monthly dung collected from private source (in 000 kcl)	140	134	0	3281
Monthly crop residues from private source (in 000 kcl)	211	377	0	6932
Monthly wood collected from private source (in 000 kcl)	314	317	0	4982
Monthly private energy collected* (in 000 kcl)	665	887	0	8764

* Collection of private energy is the total amount of wood, crop residues, and dung collected from private sources.

It can be calculated from Table 1 that the amount of fuelwood collected from commons represents about 50 percent of the total fuelwood collected from any of the sources (i.e., both commons and private trees), and 32 percent of the total biomasses used in the area. Fuelwood collected from any source consists about 64 percent of total biomasses fuel. This shows that fuelwood, in general, plays a significant role in domestic fuel use of households considered in this study. This figure can fairly be compared to estimates of the rural Ethiopia, which share of fuelwood (from all sources) constitutes about 72 percent (Alemu and Tekie, 2003).

[11] The conversion factors we used for each 1-kilogram- of fuelwood, dung and crop residues are 3500 kcl, 3000 kcl and 3200 kcl respectively while for a liter of Kerosene is 9470 kcl. Sources: ENEC in Alemu (1999) and Hosier (1985).

We observed that households in the sample are not all involved in collection of fuelwood from commons as well as private energy. Out of the total households considered in this study, about 592 (i.e. 45% of the sample) and 1056 (i.e. 81 percent of the sample) are involved in production of commons fuelwood and private energy respectively. As indicated in Table 1, each household spent, on average, 23.7 hours per month to collect the mean monthly commons fuelwood. This indicates the average labour product of households in common fuelwood collection is about 3.8kg per hour. Different household members were involved in collection of common fuelwood and no hired labour was used.

The role of fuelwood market is not that much active in the study area. From the total respondents considered in this study, only seventy-one households (about 5 percent of total households and 12 percent of those households participated in collection of commons fuelwood) reported selling of commons fuelwood. The share of this marketed commons fuelwood consists 6 percent of the total fuelwood collected from commons. This implies that collection of commons fuelwood for own consumption seems to be a more crucial factor that lies behind forest degradation than the role of fuelwood market.

Similarly, the role of market for private energy appears to be very limited. The number of households that supply private energy for market represents five percent of the total sample or six percent of those who produced the fuel in question. The share of the market sale represents nearly one percent of the total collected private energy. This may indicate that the main reason for production of private energy seems to have developed as a coping strategy of households to scarcity of commons fuelwood than as a means of income generation from market sales.

The conditional means of each relevant variables used in the analysis of this study are provided separately for the whole sample, commons fuelwood and private energy collectors in table 2. Since some households are consumers of both fuel types, conditional means of some variables for the two sub-samples are some times higher than means of the whole sample. This implies that households with large number of these variables (higher than means of the sample) are involved in collection of both fuel types.

Table 2. Means with standard errors in parenthesis of relevant variables for all households, for commons fuelwood collectors and for private energy collectors

Variable Name	All Households	Commons fuelwood collectors	Private energy collectors
Monthly fuelwood collected from commons in kcl (000)	313 (510)	692 (599)	-
Time spent collecting fuelwood from commons	23.7 (48.7)	51 (58.7)	-
Monthly private energy collected in kcl (000)	665 (887)	-	823 (918)
Number of male	2.17(1.3)	2.05 (1.26)	2.29(1.3)
Number of female	1.92(1.06)	1.89(1.04)	1.97(1.07)
Household size	5.32 (2.17)	5.19(2.22)	5.51 (2.17)
Number of cattle	5.76 (59.4)	5.86 (44.9)	5.91 (62)
Number of tree	243 (1139)	209 (1328)	258 (1214)
Land holding size	1.33 (1.12)	1.46 (0.99)	1.37 (1.17)
Improved stove indicator [a]	0.021 (0.14)	0.027 (0.16)	0.018 (0.13)
Off-farm participation indicator [a]	0.31(0.46)	0.34(0.47)	0.29(0.45)
Annual income	1869(1744)	1908(1598)	1960(1825)
Adult equivalent income	716(709)	761(702)	725(723)
N	1308	592	1056

[a] One if household with the attribute, and zero otherwise.

Endowments of the households seem to vary between the sub-samples. For example the average number of cattle for the whole sample is 5.76. The means for commons fuelwood and private energy collector households, the average figures are 5.86 and 5.91 respectively. As stated above, the higher means of both sub-samples compared to means for the whole sample implies that those households having large number of cattle (above than the mean for the sample) are involved in collection of fuelwood from commons and private energy.

The average number of trees for the whole sample is 243 per household. The figure considerably differs for the sub samples. Households that pursue collection of private energy, each own on average 258 trees, while for those collectors of commons fuelwood the average figure is 209. Since the number of trees variable is included in the model with the expectation of positive influence on private energy through increasing the availability of wood, branches or leaves, the difference on the mean of tree ownership in the two sub-samples may support the argument.

The mean land holding size for the whole sample is about 1.33 hectare. Concerning the two sub-samples, there is no clear difference in the average land holding size. The means of each sub-sample are slightly higher when compared with the mean of the total sample, although commons fuelwood procurers on average own somehow higher land size than that of private energy collectors. Once again, the higher conditional mean of the two sub-samples shows that some households owning land higher than the mean size are involved in both activities (collection of both fuel types).

To some extent, the off-farm employment opportunity in the sample area is observed to exist. About 31 percent of the total respondents were able to involve in off-farm employment with different number of days against cash payment. As shown in table 2, about 34 percent of the fuelwood collectors from commons were involved in off-farm employment, while 29 percent of the collectors of private energy were involved in off-farm employment.

The dissemination of improved stove in the area is very limited. Majority of the sample households, i.e., about 83 percent use traditional three stone stoves. About 15 percent of the sampled households possess circular stove made from mud. Of these two, owners of three stone stoves dominated the sample respondents that account for 84 percent. Households that own metal stove, *Burayu* or *Lakech* (categorized as improved stoves for this study) altogether represent only 2 percent.

Average annual income per household is *Birr* 1869. Most of the income is generated from on-farm work. Since agricultural products were reported in kind, market prices of each product faced by the households were used to convert income of households. When prices are not stated for some products of the households, prices were imputed using the mean for the Kebele, Woreda, zone or the sample area depending on availability the data. Expenditures on agricultural inputs (such as spending on tools, fertilizers & seeds) are excluded from the total income. As there is no available information on price of land and labour, we are not able to deduct from the stated income. Other sources of income including returns from rented out farm endowments such as land and oxen are also aggregated. Looking at the two sub-samples (Table 2), average annual income of a household is relatively higher for private energy collectors than that of commons fuelwood collectors.

5.2. Analysis of Fuel Estimation Results

In suspecting of sample selection bias, a Heckit method expressed in equation (26) was applied in estimation of the three equations 21 (a-c). In order to test and correct for sample selection bias - due to unobservability of the amount of fuel collected for non-collecting households - we need to estimate a probit model for fuel choice.

5.2.1. Probit Estimates of Fuel Choices

In the probit model of fuel choices, the following explanatory variables are included: dummy for household head education (1 if at least grade three), dummy for large number of cattle ownership (1 if owns at least 3), dummy for large land size (1 if land size is greater than one ha.), dummy for large number of tree ownership (1 if owns at least 50 trees), dummy for sex of household head (1 if male), dummy for older household head (1 if at least 40 years age old), improved stove ownership, interaction of large household (1 if five or more members) and number of adult members, indicator of access to training (1 if the head got some sort of training opportunity in the local area) and site dummies.

The results from probit models of fuel choices (the choice of fuelwood collecting from commons and forests; and the choice of private energy collecting from own sources) are given below.

Table 3. Fuel Choice: Probit Results with Values in brackets are standard errors.

Explanatory Variables	Dependent Variable	
	Commons Fuelwood =1	Private energy = 1
Dummy for household head education	-0.143 (0.115)	0.047 (0.137)
Dummy for large land size	-0.180* (0.104)	0.441*** (0119)
Dummy for large number of cattle ownership	-0.261*** (0.08)	0.735*** (0.111)
Dummy for large number of tree ownership	-0.381*** (0.086)	0..331*** (0.100)
Dummy of household sex	-0.063 (0.115)	-0.014 (0.128)
Dummy for older household head	-0.130 (0.091)	0.016 (0.105)
Dummy for improved stove	0.459* (0.267)	-0.364 (0.287)
Interaction of large household adult household members	0.026 (0.091)	0.148 (0.115)
Indicator of access to training	0.056 (0.081)	-0.247*** (0.270)
D. Elias[a]	-0.996*** (0.185)	1.708*** (0.260)
Kebi[a]	0.107 (0.20)	0.852*** (0.191)
Wolikie[a]	-1.379*** (0.192)	1.467*** (0.227)
Telmia[a]	-1.681*** (0.202)	1.108*** (0.205)
Sekla Debir[a]	-0.703*** (0.197)	0.704*** (0.191)
Kete[a]	-2.615*** (0.228)	2.297*** (0.255)
GodGuadit[a]	-2.257*** (0.223)	2.254*** (0.262)
Amba Mariam[a]	-1.30*** (0.211)	1.122*** (0.216)
Yamed[a]	-1.301*** (0.201)	1.317*** (0.211)
Adis Mender[a]	-1.792*** (0.210)	2.320*** (0.285)
Chorisa[a]	-1.080*** (0.198)	1.117*** (0.205)
Constant	1.562*** (0.251)	-0.611** (0.270)
Log likelihood	-706.22	-492.4
N	1308	1308

Note; (1) [a] The reference Kebele is Amanuel, located at Machak Woreda of East Gojam.
(2) ***, **, and * represent significant at 1, 5 and 10 per cent probability respectively.

The results for probit equation of fuelwood choice (the choice of fuelwood collecting from commons) are presented in column two of table 3. We found that indicators for large number of cattle and trees ownership and an indicator for large size of land ownership variables negatively influence the likelihood of choosing households to collect fuelwood from commons and forests. That is, ownership of such resources decreases the probability of households to collect their domestic fuels from commons. The dummy for improved stove, however, positively influences the probability of choosing collection of fuelwood from commons. The site dummies also matter in the fuelwood collection choice decision.

In the probit model of private energy choice - provided in column three of the above table- we found that indicators of large number of cattle, trees ownership, and large land holding size are positively related to the likelihood of choosing households to collect private energy from own sources. However, the effect of an indicator of access to training on the probability of choosing collection of private energy is found to be negative. The site dummies also influence in the private collection choice decision.

5.2.2. Analysis of Regression Results

We have checked all the three equations for sample selection problem. A significant selection bias is apparent in the fuelwood collection equation only. For this particular equation, thus, we reported results of Heckit model. In the remaining two equations (i.e. the amount of time spent on collection of fuelwood, and the amount of private energy collected from own sources), there is no evidence of a sample selection problem. Hence, these two equations are estimated by the TSLS estimation method. The multivariate regression estimates and associated errors are given in table 4 below. Results of Heckit model estimates for the fuelwood collection equation are listed in the second column of table 4, whilst results of the two stage least squares (instrument variable) for the amount of time spent on collection of fuelwood, and the amount of private energy collected from own sources are given in the third and fourth columns of table 4[12].

In the estimation equations, all the dependent variables and three explanatory variables i.e. fuelwood shadow prices, land holding size and number of cattle are entered in logarithms. The remaining explanatory variables are however in their level forms.

12 The Estimates of Heckit model for both labour time spent in fuelwood collection from commons and for collection of private energy are attached in Appendices C and D, respectively

Table 4. Estimation Results for Quantity of Fuelwood Collection, Time Spent on Collection of Commons Fuelwood, and Collection of Private energy

Dependent Variables	Amounts of Commons Fuelwood Collected	Time Spent on Collection Commons Fuelwood	Amounts of Private Energy Collected
Fuelwood shadow price	-0.855** (0.428)	0.846 (0.806)	0.226 (0.339)
Number of trees	-0.049** (0.023)	-0.028 (0.022)	0.057** (0.023)
Land size	-0.147 (0.162)	-0.035 (0.162)	0.165 (0.122)
Number of cattle	-0.116** (0.057)	-0.079 (0.056)	0.118* (0.049)
Number of male	0.089** (0.037)	0.099*** (0.038)	-0.017 (0.027)
Number of female	0.069* (0.042)	0.069 (0.043)	0.085*** (0.031)
Education level of household head	-0.058** (0.027)	-0.053** (0.026)	0.015 (0.014)
Improved stove dummy	-0.007 (0.280)	-0.232 (0.256)	-0.691*** (0.242)
D. Elias	-0.922*** (0.300)	0.570** (0.226)	0.396 (0.171)
Kebi[a]	-1.400*** (0.461)	-1.468*** (0.486)	-0.370 (0.522)
Wolikie[a]	-2.250*** (0.521)	-1.776*** (0.459)	-0.445** (0.327)
Telmia[a]	-2.237*** (0.604)	-1.638*** (0.524)	-0.139 (0.189)
Sekla Debir[a]	-0.930*** (0.310)	-0.766** (0.298)	-0.452*** (0.195)
Kete[a]	-2.665*** (0.694)	-1.384*** (0.362)	-0.352* (0.184)
GodGuadit[a]	-2.921*** (0.610)	-2.011*** (0.390)	-0.551*** (0.213)
Amba Mariam[a]	-1.083*** (0.309)	-0.662*** (0.233)	-0.796*** (0.194)
Yamed[a]	-1.756*** (0.311)	-1.305*** (0.218)	-0.911*** (0.183)
Adis Mender[a]	-1.698*** (0.433)	-1.030*** (0.263)	-0.180 (0.195)
Chorisa[a]	-1.189*** (0.268)	-0.841*** (0.196)	-0.082 (0.193)
Lambda	0.716** (0.362)		
Constant	12.642*** (0.483)	4.384*** (0.508)	12.81 (0.247)
N	592	592	1056

Note (1). All dependent variables and fuelwood shadow prices, land holding size and number of cattle are in logarithms.
(2). ***, **, and * represent significant at 1, 5 and 10 per cent probability respectively.
(3). [a] The reference Kebele is Amanuel, located at Machak Woreda of East Gojam.
(4). Values in brackets are standard errors.

Price of Commons Fuelwood

Fuelwood price is proxied by a household specific variable i.e. collection labour time per kg of fuelwood from commons. To correct for possible endogeneity of fuelwood price, we used the following instrumental variables: age of household head, household head educated level, number of adult males and females, distance between homestead and forest, indicator of credit access (1 if the household borrowed some amount of *Birr* during the year), indicator of access to training (1 if the head got some sort of training opportunity in the local area), number of livestock owned, interaction of land size and number of tree, interaction of land size and number of cattle, interaction of number of cattle and tree, indicators of future expectation in land holding size changes and the site dummies. All variables used in the regressions were also included. The instrument variables altogether explain about 35 and 30 percent variation in collection time per unit of fuelwood for the fuelwood and private energy collectors, respectively[13]. The correlations of fuelwood prices with their respective predicted values for fuelwood collectors from commons and collection of private energy are about 0.59 and 0.54, respectively.

The results indicate that the fuelwood price– as measured by collection time per kg of fuelwood from commons - in the fuelwood collection equation has a negative sign as expected, and its estimated parameter is significant at the one percent significance level. This suggests that households are responsive to fuelwood scarcity. That is, as collection time increases for a unit kg of fuelwood, households lower the amount of fuelwood collected from commons. The parameter estimate of the variable shows that for one percent increase in the amount of time required to collect one kg of fuelwood, households reduce the amount of

[13] Estimations of the virtual prices of fuelwood on the instrumental variables are attached in Appendices A and B.

fuelwood collection by 0.86 percent. It indicates that commons fuelwood collection in the study area is own-price inelastic.

As the total labour time spent on commons fuelwood equation is concerned, collection time per kg of commons fuelwood has a positive impact. This direct relationship suggests that total labour time of households allocated in commons fuelwood allocation tends to increase when the collection time per kg of fuelwood gets higher and higher. The parameter estimate of the variable in this function is, however, statistical not different from zero.

Regarding private energy, fuelwood price has a positive influence, as expected, indicating that households tend to consume private energy as price of commons fuelwood collected is becoming high. However, the variable is found to be statistically insignificant.

The results for the impact of price of fuelwood collected from commons on rural domestic fuel collection are consistent with findings of other studies. Although not directly comparable, Alemu (1999) found that woody biomass (collected from all sources i.e. from private as well as commons) is sensitive to its own price. Another finding similar to our study is the work of Heltberg et al. (1998). Their results show that fuelwood price (as measured by collection time per unit of fuelwood from forest) is inversely related to the amount of fuelwood collected from commons, and directly related to private energy, although the elasticities are somewhat lower. Similar to the case at hand, their estimate of the variable appeared statistically insignificant for the latter fuel type.

Number of trees

Number of trees planted in own fields has the expected signs in all the regressions. It has a negative effect on the amount of fuelwood collected from commons and the estimate is statistically different from zero at five percent significance level. This indicates more trees in own field are associated with lowering the amount of collected commons fuelwood. Although it has also a similar impact on the total labour time spent on fuelwood collection, its parameter estimate is statistically insignificant.

The impact of trees on consumption of private energy is positive, as expected, and the parameter estimate is statistically significant at five percent significance level. The direct relationship of number of trees and collection of private energy indicates that growing more trees on own field facilitates the consumption of private energy positively. This is most likely to come through easing the access of wood and branches from trees grown on private field.

The magnitude of the estimated parameters are, however, not that much substantial. The estimates of the variable show that additional one percent rises in the number of trees privately grown is estimated to reduce the mean annual commons fuelwood collection by 0.049 percent and to increase the mean annual private energy consumption by 0.57 percent.

The economically insignificance of the variable is surprising but this could probably be explained by the idea that the primary reason for planting trees may be aimed at getting other benefits including additional income from sales of trees products other than to use it for domestic fuel. As noted earlier, only 5 percent of the households did involve in marketing their private wood. Since the most commonly planted private trees are eucalyptuses, the gain may be derived from selling as poles and construction materials. The cash income generated from selling of trees was also reported as the most important motive for growing trees in the study area.

The impact of tree is relatively high in increasing collection of private energy than in reducing the collected amount of fuelwood collected from commons and forests. The opposite signs of the variable in the commons fuelwood and private energy regressions, as expected, may indicate that the two fuel types seem to be substitutable.

Landholding size

The land size is inversely related to both the amount of fuelwood collected from commons, and collection labour time of fuelwood. And, it influences the amount of private energy collection positively. The direct relationship of the variable with private energy is due, probably, to its augmenting effect on the availability of crop residues from plot - that is considered as part of private energy in the study.

However, unlike in the probit equations, these parameter estimates are not statistically different from zero, suggesting that land size do not significantly explain differences in collection of both fuel types. The insignificance of land holding variable in the regressions may be due to the continuous redistribution of agricultural lands and the periodic droughts that rule out the variation in the advantage of gathering crop residues to exist. Some households covered in the sample area also reported that they rented out their land to other households, which prohibits them from accessing the crop residues during the production cycle.

Cattle ownership

Number of cattle owned is found to be statistically significant at 5 percent level of significance in the regression of fuelwood collections from commons. It influences the amount of commons fuelwood collected negatively. The negative sign for the coefficient of the variable could be explained by the fact that households with more cattle have more access to dung, which could be used as domestic fuel, hence, lowering the amount of fuelwood collected from commons.

The effect of the variable in the collection of private energy equation supports the above argument. The result of the regression shows that ownership of cattle is directly related to the collection of private energy. This is probably through the effect of cattle in increasing the access of animal dung to owners.

A 10 percent increase in cattle ownership results in raising collection of private energy by about 1.2 percent, and reducing the amount of commons fuelwood collected by nearly the same percent. This demonstrates that households having large number of cattle able to substitute private energy for commons fuelwood.

Household size

Both the numbers of male and female household members are entered as explanatory variables separately in all regressions. Both variables have positive influence on the amount of fuelwood collected from commons and labour time spent on collection of this fuel type. Coefficient of the number of males is statistically different from zero at five and one percent significance levels in the functions, respectively. The parameter estimate for female members is also significant in the collection of fuelwood from commons at ten percent level of significance, but insignificant in the labour time of fuelwood collection.

The positive influence of the two variables on the collected amount of fuelwood from commons and collection labour time can be interpreted as consumption effects. That is, households with large family size would have higher fuel demand and this may drive the households for more collection of fuelwood from commons. Apart from these consumption effects, the results may also interpret as the presence of decision-making process of households about their labour allocation. In the labour time of fuelwood collection from commons and forests, only males are engaged and significantly contributing to production of the fuel. One possible reason for engagement of males in the activity is that collection of fuelwood from commons can be large stems that are too heavy to females to carry from a long distance. In this case, return to male collection can be higher than that of female members. The parameter estimates of the two variables in fuelwood collection from commons and forests show that the estimated return for males, holding other factors fixed are higher than their counter parts.

We also observe that females are the only significant collectors of private energy. The impact of males on collection of this fuel type is not only insignificant but also the magnitude of the coefficient is about five times less than that of females. The availability of resources for private energy near homesteads could probably be accounted for the significant contribution of females in the collection of private energy.

The findings, therefore, seem to be consistent with the idea that labour allocation of households is directed by economic rewards rather than the conventional view -that collection is simply a female task. Linder–Rahr (1999) also has similarly found significant contribution of men in fuelwood collection.

Improved stove

In all regressions, the improved stove indicator takes a negative sign, as expected. The estimated parameter is statistically different from zero only in collection of private energy at one percent significant level, but insignificant in the rest two regressions. The negative sign of the variable in collection of private energy suggests that households having improved stoves consume less domestic of the fuel type relative to those do not own. This is compatible with the theory that improved stoves have greater heat efficiency as compared to the traditional open stove. Among the three regressions, the improved stove indicator has large coefficient in the private energy collection, implying high magnitude of influence on lowering the amount of private energy consumption. The estimates indicate, households owning an improved stove use, on average, 50 percent less private energy than their counterparts do. The explanation for the insignificance of improved stove in consumption of fuelwood collected from commons is not clear, however.

Education level of household head

The variable takes on an inverse relationship in collection of fuelwood from commons and forests; and collection labour time of fuelwood equations. The coefficients are significant at five percent. The negative sign of the variable – entered in the regressions to account for unobserved labour market opportunity - implies that households reduce the amount of fuelwood collected from commons as the education level of the head increases. This is more likely to happen by redirecting labour time from fuelwood collection to other income generating activities. This is consistent with our expectation. As collection of fuelwood from commons is a relatively labour intensive task, the negative impact of the variable on the collected amount of the fuel is through reducing the availability of labour time left for the activity. By increasing opportunity cost of labour, then it lowers the amount of fuelwood collection from commons there by rehabilitating the environment. Conversely, households with low level of educational background are likely to have limited access for such off-farm activity, their relatively available labour, therefore, can leave them to be dependent more on collection of commons fuelwood.

The coefficient of the variable is not statistically different from zero in the private energy regression, implying that it has no effect on explaining differences on private energy collection.

Site indicators

The site indicator variables are included to reflect the differences in relative forest stock, slop (terrain of the sites), and weather which could affect collection of fuel among the sites.

In general, the regression results indicate that the key variables that are influence collection of domestic fuel types are endowment profile (ownership of land, cattle, and tree), education level of household head, and household size. Households with less asset endowments, large family size, and limited access to off-farm employment opportunity (as captured by education level of household head) are more likely to produce their domestic fuel from commons and forests. Worth mentioning is also that, those variables seem to be the underlying factors that exert pressures on degradation of commons resource.

6. CONCLUSION AND POLICY IMPLICATIONS

Fuelwood is the crucial source of domestic energy in Ethiopia. In rural area of the country in particular, collection and consumption of fuelwood are linked to natural resource management. Its increasing use up, which goes partly with population growth, has had an adverse impact on the ecological balance, and has extended to harm food production potential of the country. Deterioration of the country agro systems, on which its economic development is highly dependent, has continued in stages. The forest stock of the country has continuously been shrinking at alarming rate. About 40 percent of the country's land area, which was estimated under forest cover at the beginning of the century, has now remained below 3 percent. Whether the excessive fuelwood consumption of households has a contribution to this trend remains debatable, its collection from the increasingly scarce supplies is becoming burdensome for many rural households.

At present, the extent of modern fuel contribution to the rural households' energy consumption pattern is placed marginal. Even in the near future, the possibility of rural households' switching from fuelwood to modern fuels seems to be impractical due, mainly, to its impact on balance of payment of the country. This imposes the country, specifically of the rural households, to gather fuelwood at a cost of more labour time at least for the coming foreseeable future.

Beside to such direct consequence of fuelwood shortages, there exist a number of externalities with far reaching ramifying effects that are by no means limited to the energy sector. It may result in reducing number of cooked meals and dietary pattern that can adversely affect their welfare.

In all, fuelwood collection from commons and consumption in rural Ethiopia given its discernible association with environmental deterioration as in the foregoing, and its impact on living standard of households can complicate the situation of achieving food security and poverty alleviation agenda of the country. The far-reaching fuelwood related problems in the rural area, thus, seem imperative to exert an effort into analysis of the situation.

6.1 Conclusion

Once again, this study is motivated by the view that the increasing deforestation trend in the country makes collection of fuelwood from commons a difficult task and a continuous dependency on it, in turn, can extend to the environment and welfare issues. In light of such a proposition, the study, basically addresses two economic questions related to household energy consumption in rural Ethiopia.

The first attempt is to analyze the major factors that determine collection of domestic fuel from different sources. It mainly focuses on investigating variables that influence collection of fuelwood from commons and collection of private energy generated from own sources. Second, it examines if the two sources of fuels are substitutes or not. This is to see the existence of private energy substitutes for fuelwood collected from commons so that policy interventions can be justified to play their effective role in preserving the scarce commons resources.

In order to investigate these issues, an analytical non-separable household model for domestic fuel demand and supply was developed. The model was estimated using primary data from rural highlands of Ethiopia. Because of the non-separability between collection and consumption decisions, caused by imperfection of fuelwood markets, we used virtual fuelwood prices as explanatory variables instead of market price.

Overall, the results support the theoretical model. Fuel collections in the study area significantly respond to household endowment profiles, fuelwood collection time and household demographic characteristics. Moreover, directions of the effects are all in line with expectations.

Collection time spent for a unit of fuelwood is used as a measure of virtual prices of fuelwood and TSLS (Two Stage Least Squares) estimation technique is applied. The results showed that the variable significantly influences collection of commons fuelwood negatively. This is indicative of the fact that households are responsive to fuelwood scarcity. Households indeed collect less of fuelwood from commons, as its cost of collection is getting high. In the total labor supply to commons fuelwood equation, the impact of fuelwood price was found to be positive implying; households also tend to increase their total labour time spent in commons fuelwood collection.

Parameter estimates of the variable, however, revealed that households respond to scarcity of commons fuelwood supplies by reducing more of energy consumption than by either increasing their labour supply to collection or substituting between fuels.

The relative scarcity of private energy in the model was captured by the effect of non-price variables including farm size, number of trees growing on own field, and animal stock on fuel mix. According to the estimation results, endowment profiles positively influence collection of private energy. Specifically, households that are better off in owning large number of trees and cattle have an advantage to collect more of private energy through increasing the availability of wood and animal dung for burning, respectively. Conversely, households faced with scarcity of these resources are less able to procure private energy, in conformity with the analytical model.

Concerning household composition estimate variables, both the number males and females were found to be positively related with collection of domestic fuel. The two variables appeared to have significant contribution to commons fuelwood collection, but only females found to be significant in collection of private energy. The significant contribution of males in collection of commons fuelwood may be due to the fact that collection of fuelwood from commons requires more effort, as the supplies are located far from the homesteads. In such a case, the returns of females are likely to be smaller than their male counterparts. The parameter estimate of the results also supports the argument. The marginal contribution of males in collection of commons fuelwood is slightly higher than that of females. With respect to collection of private energy, however, the contribution of females is higher than males, with the latter variable being statistically not different from zero. The result is fairly expected, in the sense that females could have the advantage of higher contribution towards collection of private energy, as supplies for such fuel are available within their premises.

Interestingly, the results seem in agreement with that of Cooke et al. (2001). The view supports, labour allocation of rural households is guided by economic return than the conventional argument that fuel collection is simply a female task. In such circumstances, they stated that men become more involved in collection of fuelwood. The involvement of adult male with a significant contribution to fuelwood collection from commons may be, as the above authors asserted, the result of increasing fuelwood scarcity.

Education level of household head has resulted in decreasing the amount of commons fuelwood collection. This effect of the variable is expected to come about through the redirecting of labour supply of households from commons fuelwood collection to other activities. This was visualized in the regression result of labour supply to commons fuelwood collection, the variable negatively being related with the endogenous variable.

The effect of household head education on collection of private energy was found to be insignificant, although it takes a negative sign. The easy access to collection of private energy, together with the limited access of females (the only important collectors of the fuel) to the off-farm employment opportunity could explain why the variable is so insignificant.

As the off-farm employment opportunities increase the marginal value of labour, household heads with better educational background reduce their total time spent on collection and the amount of collected commons fuelwood. This implies that those households who have the opportunity to involve in off-farm employment seem to develop a new strategy. That is, they practice economizing on fuelwood use rather than to increase other fuel consumption. Therefore widening and encouraging of labour market (off-farm employment) opportunities in rural areas have a great importance in balancing the adverse effects of ecology, besides to the income those households can generate from.

The energy conversion technology to end use, proxied by improved stove ownership, entered the regression exercise with the expectation that it can influence fuel requirement of households with the opposite direction. This is because, these technologies are supposed to increase end use efficiency and, thereby, reduce pressure on forests. The empirical result for the indicator was not that much encouraging. Although, in all cases, the technology took negative sign as expected, it appeared insignificant in both the amount of commons fuelwood collected and time spent in collection. In contrast, and surprisingly enough, it was found to be significant in private energy. The reason why the indicator is not statistically different from zero in the collection of fuelwood from commons regression is obscure and requires further investigation. From the result, it can be understood that improved stoves are not immediate technical substitutes for commons fuelwood.

To determine whether the two fuel types, (fuelwood from commons and private energy) are substitutes or not, indirect cross price elasticities were evaluated. That is, through the impact of virtual prices of commons fuelwood (as measured by collection time per kg of fuelwood from commons) on collection of private energy; and through the effects of land holding size, number of trees and cattle on collection of commons fuelwood. The results showed that the two fuel types are gross substitutes, although some of the variables were insignificant.

Virtual price of commons fuelwood had positive influence on the amount of private energy collection, albeit significantly. The impacts of land holding size, number of trees and cattle owned, which were directly correlated with collection of private energy, were found to be negative on collection of fuelwood from commons and forests. And, all except the former appeared statistically significant. Hence, the results suggested the existence of substitutability between the two fuel mix, i.e., substitution from consumption of commons fuelwood to private energy is induced by increasing collection time per kg of commons fuelwood, larger farm land holding, number of trees and cattle ownership. Many of the implied elasticities were, however, low. This indicates that increasing forest scarcity alone cannot bring a substantial reduction in commons fuelwood collection to avoid the associated problems.

Worth mentioning, although substitution of private energy for commons fuelwood was observed to respond fuelwood scarcity, it seems feasible only to households with better assets (land, cattle and tree) that facilitate the process.

6.2 Policy Implications

As indicated by the regression results of the fuel collection specifications, most of the estimated elasticities are low. The significance of the most important variables with the hypothesized effects and the substitutability of commons fuelwood and private energy, however, tend to readily vindicate the need for policy interventions. By encouraging people towards production of domestic fuel of own sources, policy measures can halt forest degradations and associated problems.

Once again, fuelwood collection from commons is negative to own price, implying that households are sensitive to cost of time spending on collection of commons fuelwood. Increasing forest stock through afforestation program then lowers the cost of time spent to collect commons fuelwood could benefit households to spend their labor time for on and off-farm, nutrition, childcare and other activities. On the other side, reducing the collection time through increasing forest stock can discourage the substitution of private energy to commons fuelwood. That is, a policy intervention targeted only at enhancing the stock of commons and forests can induce people to depend more on commons fuelwood and hardly use privately produced fuel since cost of the former fuel type as measured by collection time is likely to be inexpensive. This situation can lead to forest degradation. One important implication of this study is, therefore, policy interventions seeking to increase the forest stocks through the usual reforestation and plantation works alone could have a limited impact unless the underlying factors causing commons degradation are addressed.

The use of commercial fuels and improved stoves in the study area is very limited. This could be expected due to the fact that people are reluctant to pay for modern fuels, as the relative cost of fuelwood is low or can be collected free of charges from commons. Commercial fuel availability may not be reliable. Under this condition, encouraging people towards the use of commercial fuels through subsidies will have little impact especially for those rural households residing close to forest and are also not likely to help the poor. Moreover, the cost of subsidies on the government budget may be restrictive to adopt such an alternative.

One possible area of intervention is, thus, encouraging people to substitute private energy for commons fuelwood. Important to note along side this is that burning of dung and crop residues for fuel may have an adverse effect on soil fertility. This makes unwise to direct these products towards fuel. Therefore, policy interventions should concentrate on supporting both agro forestry and plantation of tree on private fields. The interventions should target at increasing both the number and productivity of trees grown on private fields. Growing trees privately have positive externalities that are by no means limited to the energy sector. Some of these are reducing forest degradation, soil erosion, and provision of additional cash income, which could warrant public support for the success. Policy measures, to this end, need to include provision of subsidized seedling, selection of high-performing tree species, enhancing information to farmers, and other incentives for planting and continued growth of trees.

Another implication of this study casts an insight into the win-win effect of education of household head, in both rural fuel and poverty issues. As discussed earlier, off-farm employment has a desirable impact on environment by lowering the amount of fuelwood collected from commons. Because education of household head increases the opportunity cost of labour, households can shift their labour from fuelwood collection to probably other income generating activities.

In light of this, off-farm employment can help in reducing the current pressure on forest degradation. The rural development and the on going poverty alleviation policies of the government need to incorporate measures that favour the growth of off-farm employment and inducing rural people to involve in the sector. To this end policy packages may need to include increasing access to market, access to credit, encouraging private sector and non governmental organizations in creating environment friendly micro rural business, provision of relevant training that enables to take advantage of off-farm employment and other institutional support that help the program.

In so far as with energy conversion technology is concerned, improved stoves may not appear as immediate technical substitute for commons fuelwood. Dissemination of improved stove in the study area is very limited. Less than 3 percent of the total households owned the improved stoves, indicating dissemination of the technology is very restricted. Different reasons can be advanced for such low adoption of the technologies. Cost of the stoves technical mismatch to the traditional cooking habit and failure of marketing and promoting of the stoves may be some of the factors accounted for the current restricted practice. As commercial fuels are not alternative fuel types, especially for those poor rural households, it is commendable to support improved stoves that use biomass resources as inputs.

By and large, policy interventions should focus on technology dissemination, and improving technical performance of stoves in the context of actual household conditions of the poor. For rapid penetration of appropriate and cost effective modern stoves, involvement of private sector in production and delivery of the technology is crucial. To this end, policy measures need to involve such tasks as creating legal, fiscal and regulatory framework conditions, incentive mechanisms and institutional support for information dissemination.

sector in production and delivery of the technology is crucial. To this end, policy measures need to involve such tasks as creating legal, fiscal and regulatory framework conditions, incentive mechanisms and institutional support for information dissemination.

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APPENDIX

Appendix A: OLS Estimation of Fuelwood Price on Instrumental Variables for Fuelwood Collectors from Commons

Source	SS	df	MS
Model	122.768839	28	4.3846014
Residual	231.898207	563	.411897349
Total	354.667046	591	.600113446

Number of obs	=	592
F(28, 563)	=	10.64
Prob > F	=	0.0000
R-squared	=	0.3462
Adj R-squared	=	0.3136
Root MSE	=	.64179

lncfwprcel	Coef.	Std. Err.	t	P>|t|
crditdmy	-.0116374	.0664886	-0.18	0.861
lnnlstkown	.0447464	.0574676	0.78	0.437
agehhh	.0021073	.0020994	1.00	0.316
trngdmy	-.1237605	.0926176	-1.34	0.182
landecrese	.068859	.0885043	0.78	0.437
landincrease	.074446	.0743417	1.00	0.317
dstnfst	-.0010762	.0012755	-0.84	0.399
landtree	.000031	.0000669	0.46	0.643
ctltree	-4.28e-06	.0000161	-0.27	0.790
ctlland	-.0095308	.0045596	-2.09	0.037
lnnctlown	-.0022025	.0691461	-0.03	0.975
lnlndsiz	.1452407	.125452	1.16	0.247
lntree	-.0261363	.0143788	-1.82	0.070
male	-.0154802	.0259529	-0.60	0.551
fmal	-.0083821	.0291203	-0.29	0.774
grade	-.033839	.0141163	-2.40	0.017
dyimps	-.0696061	.1713446	-0.41	0.685
k2	-.3371264	.1133903	-2.97	0.003
k3	-1.048922	.1047414	-10.01	0.000
k4	-.9395594	.138287	-6.79	0.000
k5	-1.062354	.1476864	-7.19	0.000
k6	-.5785241	.1076909	-5.37	0.000
k7	-.2866934	.22468	-1.28	0.202
k8	-.5181713	.1918795	-2.70	0.007
k9	.2312748	.1404622	1.65	0.100
k10	.2266779	.1366061	1.66	0.098
k11	-.3359069	.1532415	-2.19	0.029
k12	-.2066891	.1245967	-1.66	0.098
_cons	-1.217649	.1715126	-7.10	0.000

Definition of Variables

lncfwprcel = Log of fuelwood price (collection time per unit of fuelwood)
crditdmy = Indicator of credit access (1 if the household borrowed)
lnnlstkown = Log of number of livestock owned
agehhh = Age of household head
trngdmy = Indicator of access to training (1 if the head got some sort of training opportunity in the local area)
landecrese = Indicators for increasing of future expectation in land size
landincrease = Indicators for decreasing future expectation of land size
dstnfst = Distance between homestead and forest
landtree = Interaction of land size and number of tree
ctltree = Interaction of number of cattle and tree
ctlland = Interaction of land size and number of cattle
lnnctlown = Log of number of cattle
lnlndsiz = Log of land size
lntree = Log of number of trees
male = Number of adult males

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fmal          = Number of females
grade         = Household head educated level
dyimps        = Indicator for ownership of improved stove
k1 to k12 represent for site dummy of D. Elias, Kebi, Wolikie, Telmia,
Sekla Debir, Kete, GodGuadit, Amba Mariam, Yamed,  Adis Mender and Chorisa
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Appendix B: OLS Estimation of Fuelwood Price on Instrumental Variables for Private Energy Collectors from Own Sources

Source	SS	df	MS
Model	293.492526	28	10.4818759
Residual	701.105687	1027	.682673502
Total	994.598213	1055	.942747121

Number of obs	1056
F(28, 1027)	15.35
Prob > F	0.0000
R-squared	0.2951
Adj R-squared	0.2759
Root MSE	.82624

lncfwprcel	Coef.	Std. Err.	t	P>|t|
crditdmy	-.0281127	.0617362	-0.46	0.649
lnnlstkown	.0130527	.0528561	0.25	0.805
agehhh	.0060608	.0019339	3.13	0.002
trngdmy	.0439064	.075431	0.58	0.561
landecrese	-.0069849	.0779638	-0.09	0.929
landincrease	-.0168705	.0643379	-0.26	0.793
dstnfst	-.0009673	.0014911	-0.65	0.517
landtree	8.97e-06	.0000118	0.76	0.447
ctltree	8.31e-07	5.25e-06	0.16	0.874
ctlland	-.0013297	.0040605	-0.33	0.743
lnnctlown	-.0560514	.0637589	-0.88	0.380
lnlndsiz	-.0971077	.116953	-0.83	0.407
lntree	.0401486	.013629	2.95	0.003
male	-.0274437	.0221272	-1.24	0.215
fmal	-.0062116	.0254059	-0.24	0.807
grade	.0035926	.0121898	0.29	0.768
dyimps	.0110266	.1950141	0.06	0.955
k2	.1233309	.1343792	0.92	0.359
k3	-1.49944	.1425854	-10.52	0.000
k4	-.836739	.1418289	-5.90	0.000
k5	.16473	.1448522	1.14	0.256
k6	.1551734	.1514633	1.02	0.306
k7	.0219135	.1507487	0.15	0.884
k8	-.3702644	.1536619	-2.41	0.016
k9	-.0626752	.1638337	-0.38	0.702
k10	.019059	.1519763	0.13	0.900
k11	.1488419	.1498422	0.99	0.321
k12	.0931456	.1519607	0.61	0.540
_cons	-.5872064	.1902709	-3.09	0.002

Definitions of the Variables are the same as defined above.

Appendix C. Estimates of Heckit model for Labour Time Spent in Fuelwood Collection from Commons and Forests

```
Heckman selection model -- two-step estimates   Number of obs      =      1308
(regression model with sample selection)        Censored obs       =       716
                                                Uncensored obs     =       592
                                                Wald chi2(31)      =    465.73
                                                Prob > chi2        =    0.0000
```

	Coef.	Std. Err.	z	P>|z|
lnmcflbl				
shadowpric~w	.0668885	.4576547	0.15	0.884
lntree	-.0452773	.0249915	-1.81	0.070
lnlndsiz	-.1007674	.1710641	-0.59	0.556
lnnctlown	-.1085241	.0602113	-1.80	0.071
male	.0891057	.0389053	2.29	0.022
fmal	.0670543	.0431218	1.55	0.120
grade	-.0601763	.0271435	-2.22	0.027
dyimps	-.0736338	.2900552	-0.25	0.800
k2	-.8646678	.312343	-2.77	0.006
k3	-1.468212	.4912432	-2.99	0.003
k4	-2.221465	.5547293	-4.00	0.000
k5	-2.175008	.6432282	-3.38	0.001
k6	-.9424125	.3276834	-2.88	0.004
k7	-2.326909	.7382587	-3.15	0.002
k8	-2.767478	.6486006	-4.27	0.000
k9	-.9807878	.3250131	-3.02	0.003
k10	-1.650931	.3270336	-5.05	0.000
k11	-1.576993	.4595292	-3.43	0.001
k12	-1.125446	.2818646	-3.99	0.000
_cons	4.390181	.5151689	8.52	0.000
mills				
lambda	.5632803	.3843198	1.47	0.143
rho	0.53091			
sigma	1.060972			
lambda	.56328031	.3843198		

Definition of Variables

lnmcflbl = Log of laboour time spent in fuelwood collection from commons and forests

shadowpric~w = Log of Price of fuelwood (collection time per unit of fuelwood from commons).

The remaining variables are the same as defined above.

Appendix D. Estimates of Heckit model for Private Energy

```
Heckman selection model -- two-step estimates   Number of obs      =      1308
(regression model with sample selection)        Censored obs       =       252
                                                Uncensored obs     =      1056
                                                Wald chi2(31)      =    407.58
                                                Prob > chi2        =    0.0000
```

	Coef.	Std. Err.	z	P>|z|
lnmpengkc				
phatregpe	.2098969	.3412185	0.62	0.538
lntree	.0529127	.0237751	2.23	0.026
lnlndsiz	.1299676	.127272	1.02	0.307
lnnctlown	.094261	.054085	1.74	0.081
male	.0126447	.0278877	0.45	0.650
fmal	.0831213	.0314646	2.64	0.008
grade	.0129761	.014312	0.91	0.365
dyimps	-.6457505	.2474714	-2.61	0.009
k2	.2576851	.2177055	1.18	0.237
k3	-.4949226	.5373817	-0.92	0.357
k4	-.6048624	.3622748	-1.67	0.095
k5	.0248485	.2197161	0.11	0.910
k6	-.5084163	.2032091	-2.50	0.012
k7	-.5396143	.2595685	-2.08	0.038
k8	-.7438195	.2833918	-2.62	0.009
k9	-.8889316	.2153379	-4.13	0.000
k10	-1.027176	.2157417	-4.76	0.000
k11	-.3575614	.2612327	-1.37	0.171
k12	-.1807761	.2161066	-0.84	0.403
_cons	13.07993	.3646202	35.87	0.000
mills				
lambda	-.2472172	.2396938	-1.03	0.302
rho	-0.23747			
sigma	1.0410288			
lambda	-.24721718	.2396938		

DEDINITION OF VARIABLES

Lnmpengkc = Log of collected amount of private energy
Phatregpe Log of fuelwood price for private energy collectors
The rest variables are the same as defined above.

Declaration

I, the undersigned, declare that this thesis is my original work and has not been presented, in part or whole, in any other university or college. All Sources of materials used for this thesis have been duly acknowledged.

Name Moges Mesfin

Signature ______________

Date ______________