Food versus Fuel: Examining Tradeoffs in the Allocation of Biomass Energy Sources to Domestic and Productive Uses in Ethiopia

Dawit Mekonnen, International Food Policy Research Institute, d.mekonnen@cgiar.org
Elizabeth Bryan, International Food Policy Research Institute, e.bryan@cgiar.org
Tekie Alemu, Association of Ethiopian Micro-finance Institutes, tekiealemu@yahoo.com
Claudia Ringler, International Food Policy Research Institute, c.ringler@cgiar.org

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Abstract: This paper explores the tradeoffs between domestic and productive uses of biomass energy sources in the Nile Basin of Ethiopia using a non-separable farm household model where labor and other input allocations to energy collection and farming are analyzed simultaneously. We estimate a system of five structural equations using three stages least squares and find that use of dung as a domestic fuel source has a negative impact on agricultural productivity while, use of fuelwood is associated with increased productivity. In particular, on-farm production of fuelwood appears to provide many benefits for crop productivity and labor savings, by making fuelwood collection easier and more convenient for households. The results show that households remain reliant on multiple sources of traditional biomass fuels and that these are largely complementary. At the same time, rural households have limited options to meet their domestic energy needs, and most lack access to modern fuels and technologies. The discussion suggests ways of making domestic energy collection more efficient through policy interventions aimed at the promotion of agroforestry and increasing access to new energy-efficient technologies.

Keywords: agriculture, energy, fuelwood, gender, tradeoffs

1. Introduction

Resource requirements for global food production are becoming increasingly constrained over time as the global population increases steadily towards 9.6 billion by the year 2050 (United Nations 2013). To satisfy this growing demand for food, in much of the world, agricultural production has largely become dependent on energy-intensive inputs, such as machinery, irrigation pumps, fertilizers and pesticides. In sub-Saharan Africa, however, subsistence agriculture remains the dominant form of production with many impediments to agricultural intensification.

Ethiopia is characteristic of many countries in the region in the sense that most smallholder producers lack the capital needed to intensify agricultural production (Arizpe, Giampietro, and Ramos-Martin 2011). Therefore, though global food production and security is becoming increasingly reliant on energy-intensive inputs to agriculture, agricultural production in Ethiopia remains characterized by its limited use of such inputs. We acknowledge, though, that there were modest increases in the use of some inputs, such as fertilizers, in recent years (Sheahan and Barrett 2014).

Moreover, while the use of traditional fuel sources is declining at the global scale, it remains high and is continuing to rise in sub-Saharan Africa (Arnold et al. 2003). In Ethiopia, 81 percent of the people in the country use wood for cooking and 79 percent depend on it as their primary energy supply (FAO, 2014). Furthermore, only 23 percent of the population and only 5 percent of rural households have access to electricity, despite recent expansion in the availability of electricity (World Bank 2014). Even among those households that access electricity, the use of traditional cooking stoves is still dominant. As a result, rural households rely mainly, if not exclusively, on traditional sources of energy, including fuel wood, crop residues, and dung, for domestic purposes, such as cooking and heating.

Rural households face considerable tradeoffs in the allocation of energy sources between food production and domestic purposes. Households that rely on agricultural outputs (by-products) as a source of domestic energy and those that spend considerable time collecting energy sources for domestic purposes, such as fuelwood from woodlots or communal forests, may have less time to devote to food production. Furthermore, removing animal dung and crop residues from the field for cooking or heating purposes, rather than using these materials to improve soil health, has negative implications for future agricultural production.

Agro-forestry, in many places, is replacing cropland on rural farms. This may have potential negative implications for food security as trees compete for land with crop production (Jenbere, Lemenih, and Kassa 2012). At the same time, to the extent that agroforestry brings additional income to rural households, this may allow farmers to invest more in production of food crops.

Over the last several decades, the rate of deforestation in sub-Saharan Africa has remained alarmingly high (FAO, 2010). This has mainly been attributed to the expansion of agricultural lands (crop production) into forested areas. At the same time, however, unsustainable fuel wood collection also contributes to forest depletion, particularly around urban areas (FAO, 2009).

Increasing fuelwood scarcity has economic and food security implications for rural households that rely on biomass energy sources. Rural households spend considerable time producing, gathering, and transporting biomass fuels for domestic consumption. Fuelwood production and collection, in particular, is a major undertaking for many rural households. The literature suggests that as a result of increasing fuelwood scarcity, many households increase the time they spend collecting fuel or resort to using less preferred fuel sources, such as dung and crop residues (Amacher, Hyde, and Joshee 1993; Heltberg, Arndy, and Sekhar 2000; Damte, Koch, and Mekonnen 2012). To the extent that increased time spent on fuelwood collection reduces labor input into food production, it may have negative implications for agricultural production and the food security of rural households.

The degree to which labor allocated to fuelwood collection takes labor away from agricultural production likely depends on who in the household is engaged in fuelwood collection and when fuelwood collection takes place. It is generally assumed that women and children are responsible for the collection of fuelwood, and that fuelwood scarcity increases the burden on these household members in particular (Arnold et al. 2003). However, if these household members are not heavily engaged in agricultural production, then fuelwood collection may not take labor away from agriculture. Scheurlen (2015) found that, in Ethiopia, women are primarily responsible for fuelwood collection and that increasing collection time reduces time allocated to off-farm work rather than agricultural labor. However, other studies have shown that men also contribute to fuelwood collection, particularly when fuelwood is produced on the farm (Amacher, Hyde, and Joshee 1993). Here, men’s allocation of labor to fuelwood production and collection may imply greater tradeoffs in terms of production of food crops. Furthermore, tradeoffs may be minimized if biomass is collected and stored during slack seasons, to be used during periods where labor is required for crop production.

Rural households may respond to fuelwood scarcity by switching to alternative sources of fuel such as dung and crop residues. Use of alternative fuel sources, could also have potential negative implications for food crop production—increased use of these fuel sources implies that less would be available to use as manure or mulch in order to enhance agricultural soils.

A number of studies have examined the relationship between alternative fuel sources. The literature suggests the degree of substitutability or complementarity of different fuel sources is context specific. Many studies point to an energy ladder where users substitute preferred energy sources, usually modern fuels for solid biomass fuel sources, and adopt improved technologies as their income increases (Amacher, Hyde, and Joshee 1993; Arnold et al. 2003; Lee 2013). In Nepal, Amacher, Hyde, and Joshee (1993) found that most households substitute fuelwood for residues when they can afford to and reduce their reliance on fuelwood when they can afford improved cookstoves. On the other hand, some studies suggest that households chose to combine different fuel sources (Masera, Saatkamp, and Kammen 2000; Heltberg 2005). For example, studies on Ethiopia have shown that dung and fuelwood tend to be complementary because when both fuel sources are used together, they last longer (A. Mekonnen and Kohlin 2008; Damte, Koch, and Mekonnen 2012; A. Mekonnen 1998). To the extent that fuelwood and dung are complementary in Ethiopia, increasing the supply of fuelwood may do little to encourage the use of dung and crop residues as a soil amendment (A. Mekonnen and Kohlin 2008; Damte, Koch, and Mekonnen 2012). Households also use both modern and traditional fuel sources for different purposes in the home, like lighting and cooking (Heltberg 2005; Masera, Saatkamp, and Kammen 2000; Guta 2014; Guta 2012).

Both the energy ladder and mixed fuel theories assume that demand drives household choice of fuel sources. However, rural households, in particular, may have little control over their choice of fuel sources. That is, fuel choice is largely determined by supply-side constraints (Rehfuess et al. 2010; Guta 2012).

In addition to increasing the time spent in fuelwood collection and/or switching to alternative fuel sources, households could respond to fuelwood scarcity by engaging in tree planting, either through reforestation programs or agroforestry. A number of studies have chronicled the evolution of policies in Ethiopia regarding tree plantations and agroforestry over the last several decades (Jenbere, Lemenih, and Kassa 2012; Ayana, Arts, and Wiersum 2013; Bane et al. 2007). In order to increase forest cover and satisfy growing demand for fuelwood the government of Ethiopia established peri-urban plantations and community woodlots of fast-growing trees, such as Eucalyptus, which can be planted on degraded lands (Jagger and Pender 2003; Z. Mekonnen et al. 2007; Jenbere, Lemenih, and Kassa 2012). However, many of these government-controlled plantations were destroyed after the change of government in 1991 (Bane et al. 2007). Furthermore, due to concerns regarding environmental impacts and displacement of food crops, the government has abandoned efforts to promote planting of eucalyptus trees and some regional governments have banned planting of these trees near farmland (Jenbere, Lemenih, and Kassa 2012).

Many farmers were initially reluctant to plant trees on plots away from the homestead (Kassa, Bekele, and Campbell 2011). However, in recent years, many household have begun to plant trees on their own farms and, as a result, the supply of domestic energy increasingly comes from farmers' own fields (Bewket 2003; Jenbere, Lemenih, and Kassa 2012). Despite environmental and food security concerns, many smallholder farmers continue to plant eucalyptus, as a source of fuelwood, to increase tenure security, and to increase and diversify income (Jagger and Pender 2003; Z. Mekonnen et al. 2007; Gebreegziabher et al. 2010; Jenbere, Lemenih, and Kassa 2012). Some studies have shown that planting eucalyptus on degraded lands has a higher rate of return than crop farming (Holden et al. 2003; Jagger and Pender 2003) or that it contributes a significant share of household income (Z. Mekonnen et al. 2007).

While most farmers continue to plant trees around the homestead, on the perimeter of food crop plots, or on marginal lands, agroforestry also has the potential to displace areas planted with food crops, with negative implications for food security. At the same time, agroforestry may have positive benefits for food crop production and food security if it provides additional income which enables farmers to invest in additional agricultural inputs or if fruit are planted providing greater nutrition and food security.

Table 1: Possible trade-offs of biomass for domestic energy use versus farm uses

Fuel resource	**Effect on labor**	**Effect on agricultural land/soils**
Dung	Time spent collecting dung may reduce time allocated to agriculture. The tradeoff may be minimal if cattle are kept close to the homestead.	Using dung for fuel limits the ability of farmers to maintain soil fertility.
Crop residue	Time spent collecting crop residues may reduce time allocated to agriculture. This may be minimal if residues are collected after harvest.	Removal of crop residues for fuel will reduce soil fertility as organic matter is not being plowed back into the soil.
On farm wood	Time spent producing and collecting wood on farm may reduce labor for agriculture	The effect can be positive if wood production and sales increases investments in productivity-enhancing inputs. The effect can be negative if tree production reduces allocation of land for food crop production. Also depends on tree choice.
Off farm wood	Time spent collecting wood off-farm is likely to have only a modest impact on labor supply to farm as it is mainly undertaken by women and children during the slack season.	No direct effect. It may help households increase agricultural land as it implies less reliance on on-farm wood production.

We summarize the possible tradeoffs between the production and collection of biomass fuel resources and agricultural production identified in the literature in Table 1.

This paper explores the complex relationship between domestic and agricultural uses of biomass energy sources in detail. Questions addressed in this paper are: To what extent does reliance on traditional energy sources for domestic purposes hinder agricultural productivity? What determines household allocation of labor to collection of domestic energy sources?

The next section presents the conceptual framework used for the analysis, while section 3 describes the empirical model. Section 4 describes the data collection approach and presents descriptive statistics of key variables used in the analysis. The results are discussed in Section 5 and Section 6 presents the conclusions, policy implications, and future avenues for research.

2. Conceptual Framework

The economic agent in this study is a rural household engaged both in agricultural production and collection of biomass for domestic energy uses, such as cooking and heating. There is an expected tradeoff between biomass used for household energy and that used as an input to crop production. For instance, cow dung used for energy purposes is no longer left on the field to enhance soils or available for use as manure and/or compost. Likewise, crop residue used for energy purposes cannot be plowed in back to the field to improve the soil's organic matter. There is also rivalry for household labor used for agriculture versus that used for the collection or production of biomass for energy purposes.

Since the decisions on how much family labor and biomass to allocate towards agricultural production versus domestic energy collection and use are made by the household simultaneously, we use a non-separable household model to explore the agriculture-energy nexus. The assumption of non-separability is supported by the literature on household energy use (Heltberg, Arndy, and Sekhar 2000; Lee 2013).

The hypothesis to be tested is that households that spend more time on the collection of dung, fuelwood, and crop residues are likely to be less productive in crop production. At the same time, more productive farmers are less likely to spend more time collecting biomass for domestic energy purposes since the opportunity cost of time spent on the collection of biomass for these productive farmers is going to be higher than the market price. This is, however, assuming that farmers have easy access to alternative energy sources in the event they are able to switch to one. In the absence of access to modern energy sources and technologies, such as electric stoves, it is likely that we will see shifts within different types of traditional biomass sources in a manner consistent with the energy ladder. Rather the literature tends to support the "fuel stacking" hypothesis, in which different energy sources are combined or used for different purposes (Guta 2012; Guta 2014; Heltberg 2005; Diseases, Regional, and May 2004; Masera, Saatkamp, and Kammen 2000).

We assume that household utility (U) is additive in the consumption of energy-intensive household goods and services, such as cooked food and heating (C_E), consumption of other goods (C_O), and leisure (R).

$$U = \Psi_E(C_E) + \Psi_O(C_O) + \Psi_R(R) \qquad (1)$$

The consumption of energy-intensive goods (C_E) is a function of households' agricultural production (Q_{Ag}), off-farm income ($w_O N_{OFF}$, where w_O and N_{OFF} are the daily wage rate and the number of household labor days on off-farm jobs), as well as the number of labor days the household spends on the collection of the three biomass energy sources considered in this study - dung (N_D), fuelwood (N_F), and crop residue (N_{CR}):

$$C_E = f_{CE}\left(Q_{Ag}, w_O N_{OFF}, N_D, N_F, N_{CR},\right) \qquad (2)$$

Agricultural production depends on labor spent on crop production, N_{Ag}, a vector of agricultural inputs, as well as household and plot characteristics (X), and the amount of labor spent on the collection of dung, fuelwood, and crop residues ($N_D, N_F, and\ N_{CR}$) as proxy measures for the amount of biomass withdrawn from the agricultural field:

$$Q_{Ag} = f_{Ag}\big(N_{Ag}, X, N_D, N_F, N_{CR}\big) \qquad (3)$$

If we represent the initial family labor endowment of the household by $\overline{N}_F$, then the household time constraint can be shown as:

$$\overline{N}_F - N_{Ag} - N_D - N_F - N_{CR} - N_{OFF} - R \geq 0 \qquad (4)$$

If we define farmers' initial financial endowment as $\overline{M}$, and average prices for crops, inputs, and other goods as P_{Ag}, P_x, and P_o, then the household's liquidity constraint is:

$$\overline{M} + P_{Ag}Q_{Ag} + w_O N_{OFF} \geq P_o C_o + P_o X \qquad (5)$$

The household then maximizes utility subject to the time constraint, the liquidity constraint, and the non-negativity constraints on the choice variables.

$$\begin{gathered}
\underset{N_{Ag}, N_D, N_F, N_{CR}, N_{OFF}, X, R, C_O}{\text{argMax}} \quad f_{CE}\big(Q_{Ag}\big(N_{Ag}, X, N_D, N_F, N_{CR}\big), N_D, N_F, N_{CR}, w_O N_{OFF}\big) + \Psi_O(C_O) + \Psi_R(R) \\
\text{s.t.} \\
\overline{N}_F - N_{Ag} - N_D - N_F - N_{CR} - N_{OFF} - R \geq 0 \\
\overline{M} + P_{Ag}Q_{Ag}\big(N_{Ag}, X, N_D, N_F, N_{CR}\big) + w_O N_{OFF} \geq P_o C_o + P_x X \\
N_{Ag}, N_D, N_F, N_{CR}, N_{OFF}, X \geq 0 \\
R, C_O > 0 \qquad (6)
\end{gathered}$$

R and C_O are assumed strictly positive because their marginal utility will be infinite at $R = 0$ and $C_O = 0$, implying that some leisure is always reserved and a positive amount of other goods, C_O, is consumed.

The Lagrangean for this optimization problem becomes:

$$\begin{aligned}
\underset{N_{Ag}, N_D, N_F, N_{CR}, N_{OFF}, X, R, C_O}{\mathcal{L}} \quad & f_{CE}\big(Q_{Ag}\big(N_{Ag}, X, N_D, N_F, N_{CR}\big), N_D, N_F, N_{CR}, w_O N_{OFF})\big) + \Psi_O(C_O) + \Psi_R(R) \\
& + \beta[\overline{N}_F - N_{Ag} - N_D - N_F - N_{CR} - N_{OFF} - R] \\
& + \alpha\big[\overline{M} + P_{Ag}Q_{Ag}\big(N_{Ag}, X, N_D, N_F, N_{CR}\big) + w_O N_{OFF} - P_o C_o - P_x X\big] \qquad (7)
\end{aligned}$$

The Khun-Tucker first order conditions are as follows.

$$\frac{\partial \mathcal{L}}{\partial N_{Ag}} = \frac{\partial f_{CE}}{\partial Q_{Ag}}\frac{\partial Q_{Ag}}{\partial N_{Ag}} - \beta + \alpha P_{Ag}\frac{\partial Q_{Ag}}{\partial N_{Ag}}, \qquad N_{Ag} \geq 0, \quad N_{Ag}\frac{\partial \mathcal{L}}{\partial N_{Ag}} = 0 \qquad (8)$$

$$\frac{\partial \mathcal{L}}{\partial N_D} = \frac{\partial f_{CE}}{\partial Q_{Ag}} \frac{\partial Q_{Ag}}{\partial N_D} + \frac{\partial f_{CE}}{\partial N_D} - \beta + \alpha P_{Ag} \frac{\partial Q_{Ag}}{\partial N_D}, \qquad N_D \geq 0, \quad N_D \frac{\partial \mathcal{L}}{\partial N_D} = 0 \tag{9}$$

$$\frac{\partial \mathcal{L}}{\partial N_F} = \frac{\partial f_{CE}}{\partial Q_{Ag}} \frac{\partial Q_{Ag}}{\partial N_F} + \frac{\partial f_{CE}}{\partial N_F} - \beta + \alpha P_{Ag} \frac{\partial Q_{Ag}}{\partial N_F}, \qquad N_F \geq 0, \quad N_F \frac{\partial \mathcal{L}}{\partial N_F} = 0 \tag{10}$$

$$\frac{\partial \mathcal{L}}{\partial N_{CR}} = \frac{\partial f_{CE}}{\partial Q_{Ag}} \frac{\partial Q_{Ag}}{\partial N_{CR}} + \frac{\partial f_{CE}}{\partial N_{CR}} - \beta + \alpha P_{Ag} \frac{\partial Q_{Ag}}{\partial N_{CR}}, \qquad N_{CR} \geq 0, \quad N_{CR} \frac{\partial \mathcal{L}}{\partial N_{CR}} = 0 \tag{11}$$

$$\frac{\partial \mathcal{L}}{\partial N_{OFF}} = w_O \frac{\partial f_{CE}}{\partial N_{OFF}} - \beta + \alpha w_O, \qquad N_{OFF} \geq 0, \quad N_{OFF} \frac{\partial \mathcal{L}}{\partial N_{OFF}} = 0 \tag{12}$$

$$\frac{\partial \mathcal{L}}{\partial X} = \frac{\partial f_{CE}}{\partial Q_{Ag}} \frac{\partial Q_{Ag}}{\partial X} + \alpha P_{Ag} \frac{\partial Q_{Ag}}{\partial X} - \alpha P_x, \qquad N_{OFF} \geq 0, \quad N_{OFF} \frac{\partial \mathcal{L}}{\partial N_{OFF}} = 0 \tag{13}$$

$$\frac{\partial \mathcal{L}}{\partial R} = \frac{\partial \Psi_R}{\partial R} - \beta, \qquad R > 0, \quad R \frac{\partial \mathcal{L}}{\partial R} = 0 \tag{14}$$

$$\frac{\partial \mathcal{L}}{\partial C_O} = \frac{\partial \Psi_{C_O}}{\partial C_O} - \alpha P_o, \qquad C_O > 0, \quad C_O \frac{\partial \mathcal{L}}{\partial C_O} = 0 \tag{15}$$

If the household is engaged in dung collection, $N_D > 0$, the Khun-Tucker complementarity condition implies that $\frac{\partial \mathcal{L}}{\partial N_D} = 0$. Thus, equation (9) shows that

$$\frac{\partial f_{CE}}{\partial N_D} = \beta - \frac{\partial Q_{Ag}}{\partial N_D} \left[\frac{\partial f_{CE}}{\partial Q_{Ag}} + \alpha P_{Ag} \right] \tag{16}$$

The left hand side of equation (16) is the marginal utility of the household from the consumption of energy-intensive household goods and services using dung as an energy source. β and α are non-negative because they are Lagrangean multipliers. The price of agricultural goods, P_{Ag}, is also non-negative. Marginal utility from the consumption of energy-intensive goods made possible from increased agricultural production ($\frac{\partial f_{CE}}{\partial Q_{Ag}}$) is also assumed to be non-negative. Thus, if the marginal impact of using dung for domestic purposes on the amount of agricultural production ($\frac{\partial Q_{Ag}}{\partial N_D}$) is negative, then, the right hand side of equation (16) will be positive. The right hand side of equation (16) is, thus, the marginal impact of using dung for domestic energy purposes in terms of lower agricultural output (hence, lower consumption of energy-intensive goods, CE) and the additional burden it imposes on households' time and liquidity constraints (β and α). Thus, the household will continue using dung for domestic purposes, until the marginal utility of using dung for domestic energy purposes equals its marginal cost.[1] What remains as an empirical question is whether or not the use of dung will reduce agricultural output and the extent to which it does. So, in the empirical approach that follows, we explore whether $\frac{\partial Q_{Ag}}{\partial N_D} < 0$.[2]

3. Empirical Model

In the empirical estimation, we specify five structural equations for agricultural productivity and the number of days per year spent on the collection of dung, on-farm and off-farm fuelwood, and crop residues. Two key assumptions we made on the error terms of the structural equations determine the choice of estimator for the system of equations. First, given the presence of some right-hand-side variables that are under the choice set of the household, we assume that the error terms are correlated with one or more explanatory variables. Second, given that households make simultaneous decisions on aspects of agricultural production and domestic energy consumption, we assume that the error terms are correlated across equations. Thus, we use three stage least squares (3SLS) estimator so that we use instrumental variables for the right hand side endogenous variables while taking into account the covariances across equation disturbances to improve the precision of the estimates.

The first structural equation refers to crop productivity where the dependent variable is defined as the sum of the value of output of teff, wheat, maize, and barley per hectare. We chose these crops because of their importance in Ethiopian agriculture—combined they represented approximately two thirds of the total land under grains production in the country for the main rainy season of 2010/11 (CSA, 2011). The agricultural inputs used in the equation include labor, urea, DAP, pesticide, and oxen per hectare. Other variables used to explain the value of agricultural output include gender, age, marital status, and education of the household head, and average years of schooling in the household to capture any intra-household schooling externality. Characteristics of the farm are also included, such as average slope, soil fertility, and severity of erosion of plots; access to the public extension system; days spend on the collection of dung, fuelwood, and crop residue; and biophysical characteristics, such as rainfall and elevations. Thus, the crop production equation can be given as:

$$\begin{aligned} &Value\ of\ output/ha \\ &= F_Q(production\ inputs\ per\ ha;\ household, plot, and\ biophysical\ charactersitcs; \\ &\qquad days\ collecting\ dung, on\ and\ off farm\ fuel\ wood, and\ crop\ residues) \end{aligned} \quad (18)$$

The amount of labor days households exert on the collection of dung (N_D), on-farm fuelwood (N_{Fon}), off-farm fuelwood (N_{Foff}), and crop residues (N_{CR}) are expected to be influenced by the demographic characteristics of the household (X_{HH}), biophysical characteristics, such as rainfall and temperature, and the use of charcoal stoves. In addition, dung collection is expected to be affected by the number of livestock units (TLUs) the household owns. Moreover, time spent on the collection of crop residues is a

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[1] The same conclusion can be reached if one uses fuel wood (equation 13) or crop residues (equation 14).

function of crop prices (P), the number of livestock the household owns (TLU), as well as the value of crop output produced per hectare. We have allowed interdependencies among time spent on the collection of different energy sources by including them in each other's equation. This allows us to identify the complementarity or substitutability relationships among biomass sources for domestic energy purposes with potentially helpful implications on policy.

Thus, the days spent on biomass collection can be given as:

$$N_D = f_{ND}(X_{HH}, Rainfall, Temperature, Livestock\ ownership, output/ha, N_{Fon}, N_{Foff}, N_{CR}) \qquad (19)$$

$$N_{Fon} = f_{ND}(X_{HH}, Rainfall, Temperature, Livestock\ ownership, output/ha, N_D, N_{Foff}, N_{CR}) \qquad (20)$$

$$N_{Foff} = f_{ND}(X_{HH}, Rainfall, Temperature, Livestock\ ownership, output/ha, N_D, N_{Fon}, N_{CR}) \qquad (21)$$

$$N_{CR} = f_{ND}(X_{HH}, P, Rainfall, Temperature, Livestock\ ownership, output/ha, N_D, N_{Fon}, N_{Foff}) \qquad (22)$$

The three stages least squares (3SLS) estimation of the system of equation (18) to (22) allows us to explore the linkages between farmers' agricultural production, and level of effort they exert in the collection of dung, fuel wood, and crop residues for domestic cooking and heating purposes. These equations were also estimated using seemingly unrelated regressions (SURs). Given the SURs do not address potential bias due to endogeneity, the results of the 3SLS are preferred and are presented below while the results of the SURs are shown in an appendix.

3.1 Instrumental Variables

The structural equations include some explanatory variables that are wholly or partly under the control of farmers. This implies that OLS or SUR can lead to inconsistent estimates of the coefficients due to unobserved individual heterogeneity. However, the richness of our dataset along with the use of 3SLS has allowed us to address these issues.

The potentially endogenous variables in the crop production equation are: education status of the household head, average years of schooling for household members other than the head, days spend on the collection of dung, fuelwood, and crop residues, as well as levels of use of labor, land, urea, DAP, and pesticides per hectare of land. We use access to primary and secondary schools in the village to instrument the education status of the head and members of the household. The use of chemical fertilizers and pesticides per hectare are instrumented with the availability a farmers' cooperative in the village where farmers can buy fertilizer and other inputs, distance from output markets, and average distance of the plots from the homestead. Number of labor days used in agriculture is instrumented with the wage rate for male and female agricultural laborers in the village, the ratio of adult male to total number of adults in the house, and the number of adult relatives the household has in the village. Value of agricultural output per acre, and days spend on the collection of dung, fuelwood, and crop residues are left hand side variables in the simultaneous equation system. Distance to markets is also used as an instrument for the potentially endogenous variable of use of a charcoal stove in the three biomass equations. Table 2 provides all the list of endogenous and exogenous variables used the empirical estimation.

Table 2: List of endogenous and exogenous variables used in the estimation of the system of equations

	Explanatory variables	Exogenous/ Endogenous	Instrument
Productivity Equation (Dependent variable: value of output/ha)	Labor per ha	Endogenous	Wage rate for male and female agricultural laborers, the ratio of adult male to total number of adults, number of adult relatives in village
	Urea per ha	Endogenous	Availability of farmers' cooperative in the village, distance from output markets, average distance of the plots from the homestead, and percentage shares of clay, sandy, black, and red soils
	DAP per ha	Endogenous	
	Pesticide per ha	Endogenous	
	Improved varieties used	Endogenous	
	Extension visits	Endogenous	
	Oxen per ha	Endogenous	Average livestock size in village
	Male head	Exogenous	Self
	Head's age	Exogenous	Self
	Head's education	Endogenous	access to primary and secondary schools
	Members' years of schooling	Endogenous	
	Married	Exogenous	Self
	Soil fertility	Exogenous	Self
	Slope of the plot	Exogenous	Self
	Erosion	Exogenous	Self
	Days spent on dung collection	Dependent variable in the system of equations	
	Days spent on on-farm fuelwood collection	Dependent variable in the system of equations	
	Days spent on off-farm fuelwood collection	Dependent variable in the system of equations	
	Days spent on crop residue collection	Dependent variable in the system of equations	
	Rainfall	Exogenous	Self
	Elevation	Exogenous	Self
	Climate smart agricultural practices	Endogenous	Years of farming experience
Biomass	Male head	Exogenous	Self

Equations	Head's age	Exogenous	Self
	Head's education	Endogenous	access to primary and secondary schools
	Members' years of schooling	Endogenous	
(Dependent variables: labor days spent in the collection of dung, on-farm wood, off-farm wood, and crop residues	days spend on dung collection	Dependent variable in the system of equations	
	days spend on on-farm fuelwood collection	Dependent variable in the system of equations	
	days spend on off-farm fuelwood collection	Dependent variable in the system of equations	
	days spend on crop residue collection	Dependent variable in the system of equations	
	Value of output per ha	Dependent variable in the system of equations	
	Rainfall	Exogenous	Self
	Livestock units owned	Endogenous	Average livestock size in village
	Charcoal stove	Endogenous	Distance to markets
	Access to electricity	Exogenous	Self
	Number of trees planted	Endogenous	Village's normalized difference vegetation index (NDVI)
	Ratio of adult men	Exogenous	Self
	Household size	Exogenous	Self
	Distance to Market	Exogenous	Self
	Average temperature	Exogenous	Self
	Barley price	Exogenous	Self
	Maize price	Exogenous	Self
	Teff price	Exogenous	Self
	Wheat price	Exogenous	Self

Note: Exogenous variables included in any equation are used as instruments for any endogenous variable in the system. The table is only meant to indicate endogenous variables for which the exogenous variables are expected to have strong relevance.

4. Data Collection and Descriptive Statistics

The study utilizes data[3] collected from 930 randomly-selected households in the Nile Basin of Ethiopia in 2013. The survey was carried out between May and August 2013, covering agricultural production over the 2012 calendar year. The households are drawn from 20 peasant associations in the regions of Tigray, Amhara, Oromia, SNNP, and Benshangul-Gumuz. The number of peasant associations from each region are: 3 from Tigray, 6 from Amhara, 7 from Oromia, 1 from SNNP and 3 from Benshangul-Gumuz.

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[3] The survey was implemented by the Association of Ethiopian Microfinance Institutes (AEMFI). The survey was designed by IFPRI and CIMMYT and was supported by the CGIAR Programs on Water, Land and Ecosystems (WLE) and Climate Change Agriculture and Food Security (CCAFS).

The sampling frame was developed to ensure representation at the woreda level of rainfall patterns in terms of both annual total and variation; the four classes of traditionally defined agro-ecological zones (AEZs) found in the Nile Basin; vulnerability of food production systems (based on the frequency of food aid deliveries); and irrigation prevalence. Twenty woredas were selected such that across each of the above dimensions the proportion falling into each class for the sample matched as closely as possible the proportions for each class in the entire Nile Basin. From each of these woredas, 50 households were randomly selected from municipal rosters.

The dataset has information on demographic characteristics, wealth status, employment and sources of income, household assets, sources of water and energy, shocks, land tenure, land management, crop and livestock management, markets, credit, saving and expenditures, perceptions of climate change, adaptation, and social capital. The analysis in this paper relies on two modules in the dataset, in particular. The first module on domestic energy sources includes data on which energy sources households rely on for domestic purposes, how these are collected, the amount of time spent on energy collection, and who in the household is responsible for energy collection.

Table 3: Collection time for domestic energy sources, by gender of the main collector

	Women's average collection time (hrs/yr)			Men's average collection time (hrs/yr)		
Fuel source	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
Wood from own woodlot	295	88	66.4	391	87	56.8
Wood from neighbors' woodlots or community forest	239	125	102.6	48	108	82.4
Dung	430	95	73.5	40	61	44.2
Crop residue	172	57	55.1	26	62	53.6

While more than one household member may be responsible for collection of different energy sources, the dataset only indicates who in the household is the main collector of each energy source. Therefore, energy collection times cannot be divided amongst different household members. Nevertheless, these data provide insights into how much time households spend collecting various sources of domestic energy and who in the household is primarily responsible for these tasks. Table 3 shows average collection times by fuel source and gender of the main collector. Collection times are given in hours per year, which is calculated based on the average reported collection times during the dry and rainy seasons.

The data show that the main sources of domestic energy are fuelwood (either produced on farm or collected from neighbors' woodlots or community forests), dung, and crop residues. A large majority of households (74 percent) get at least a portion of their fuelwood from their own farm. Both men and women are responsible for this task, which takes an average of 87 and 88 hours per year, respectively. Collecting wood from neighbors' woodlots or from community forests is done by 31 percent of households and this task takes considerably more time to perform. Households in which women are primarily responsible for fuelwood collection spend an average of 125 hours per year collecting off-farm fuelwood, while households in which men are the primary fuelwood collectors spend an average of 108 hours per year.

A large proportion of households (51 percent) also depend on animal dung as an important source of domestic energy. Women are primarily responsible for dung collection, spending an average of 95 hours per year on this task. Only 21 percent of households use crop residues as a main source of domestic energy. Again, women are primarily responsible for the collection of crop residues, which takes an average of 57 hours per year.

The second module in the dataset that is of interest for this paper focuses on on-farm production of residues, many of which are used as domestic energy sources. Table 4 shows the primary residues that are produced on farm and how these residues are allocated to different purposes.

Table 4: Uses of residues produced on farm

Residue type	Obs.	Percent of hhs that collected residue type	Percent allocated to fuel	Percent allocated to crop production	Percent allocated to livestock	Percent allocated to other uses
Maize stover	351	37.8	17.3	3.8	56.9	0.7
Maize cobs	259	27.9	60.6	1.2	30.3	0.9
Teff stover	472	50.8	0.9	1.7	77.0	11.4
Cereal straw/husks	540	58.1	2.9	3.3	78.8	1.8
Legumes residue	265	28.5	1.2	2.8	79.7	1.5
Twigs, leaves, and bunches	331	35.6	79.4	1.6	8.0	0.6
Wood (not woodlots)	106	11.4	83.0	0.4	4.7	7.6
Fodder grasses	95	10.2	1.1	0.0	89.6	0.8
Cow dung	610	65.7	45.2	44.5	0.8	0.3

The main residues produced by farm households are maize stover, maize cobs, cereal straw and/or husks, legumes residue, woody residue (including twigs, leaves, branches, and wood), fodder grasses, and cow dung. The main residues used as domestic fuel include maize cobs, woody residues, and cow dung. Crop residues (apart from maize cobs) are primarily used as livestock feed, while dung is also used as manure for crop production.

5. Results

The results of the 3SLS estimation show a tradeoff between domestic and agricultural uses of energy with respect to dung (Table 5). Agricultural productivity decreases as time spent collecting dung increases. The loss in productivity is likely due to the fact that dung removed from the field for fuel cannot be used to enhance soil organic matter. The coefficient on time spent collecting residues is also negative but not statistically significant.

However, contrary to expectation, time spent collecting on-farm and off-farm fuelwood is associated with higher agricultural productivity. The results are particularly significant for on-farm fuelwood. This suggests that households that collect more fuelwood are allocating labor efficiently and that household efficiency in managing the allocation of labor likely carries over into the way in which households manage their agricultural plots, resulting in higher productivity on cropland.

It is also likely that fuelwood collection takes place during slack seasons when labor is not required for agricultural production. In addition, households may assign responsibility for fuelwood collection to members that are less engaged in agricultural production. As noted above, women are primarily responsible for biomass collection although men also contribute to on-farm fuelwood collection. In our sample, on average, men provide more agricultural labor than women (95 compared to 39 person days per year) so fuelwood collection by women is not likely to negatively affect agricultural productivity. The highly significant result on on-farm fuelwood collection suggests that there is some productivity benefit of planting trees on the farm. Timber trees may provide shade for food crops and improve soil quality. On-farm fuelwood may also provide some labor savings as fuelwood is available closer to the homestead.

Apart from biomass collection, several other factors influence productivity of barley, maize, teff and wheat. The number of oxen per hectare of land has a positive and significant impact on agricultural productivity. Productivity also increases as the fertility of the soil increases and as the amount of rainfall increases.

The biomass equations provide further support for the results shown in the productivity equation. As value of output per hectare (productivity) increases, time spent collecting dung decreases while time spent collecting on- and off-farm fuelwood increases. This suggests that more productive households collect and use more fuelwood and less dung in their domestic fuel mix.

If we consider biomass collection times to be a proxy for the quantity of different biomass sources collected, then the results also seem to provide evidence of multiple fuel use, similar to other recent studies on this topic (Guta 2012; Guta 2014; Heltberg 2005; Masera, Saatkamp, and Kammen 2000). That is, households use whatever fuel sources are available to them and tend to mix different biomass energy sources. When new or preferred sources of fuel are available, rather than switching to the alternative fuel, these are “stacked” on top of other sources of household fuel (Masera, Saatkamp, and Kammen 2000; Heltberg 2005).

In particular, the results show that time spent collecting dung increases with time spent collecting on- and off-farm fuelwood and crop residue. Similar patterns are observed across the other biomass equations with some exceptions. Crop residue does not appear to be complementary to fuelwood as the results, while positive, are not statistically significant. Not surprisingly, the results also show on-farm and off-farm sources of fuelwood are substitutes. Specifically, time spent collecting off-farm fuelwood decreases as more fuelwood is collected on-farm and vice versa. In addition, the residue equation shows that while residues and dung are complementary, there is a negative relationship between residue and on-farm fuelwood collection. This indicates that crop residues may be a less preferred source of domestic energy and that households with access to on-farm wood use less crop residues for fuel.

Even households with electricity do not appear to reduce their consumption of biomass energy sources with the exception of dung. Rather households with access to electricity increase consumption of on- and off-farm fuelwood and residues, again supporting the fuel stacking hypothesis. However, an opposite pattern is observed among households that own a charcoal stove (although fewer than 6 percent of the households in the sample have charcoal stoves). Owning a charcoal stove increases the time spent collecting dung and decreases time spent collecting on- and off-farm fuelwood, which suggests that charcoal and dung are complementary while fuelwood and charcoal are substitutes.

Planting more timber trees on-farm reduces the amount of time spent collecting on- and off-farm fuelwood, given that trees available on the farm are more readily available for fuelwood collection. This supports the notion that agroforestry provides some labor savings for rural households by making fuelwood collection more convenient. Households that have more timber trees also spend more time collecting dung which again supports the complementarity of fuelwood and dung. However, time spent collecting crop residues decreases as the availability of on-farm fuelwood increases.

Livestock ownership also has a significant impact on the use of dung and crop residues. Not surprisingly, households that own more livestock are more likely to collect more dung, which seems to indicate that households collect more dung when more of it is available. However, households are less likely to collect crop residues for fuel when they own more livestock. This suggests that households with greater livestock holdings are more likely to leave crop residues in the field for grazing their own animals rather than to collect residues for fuel.

Some demographic characteristics of the household as well as biophysical characteristics also influence biomass collection times. Surprisingly male-headed households appear more likely to collect dung. However, households in which the share of adult males is lower compared to adult females, spend less time collecting dung. On the other hand, male-headed households are less likely to collect on- and off-farm fuelwood and crop residues. In addition, larger household and those with more adult men appear more likely to spend more time collecting crop residues for fuel. Education also affects time spent collecting dung and residues, However, because we include both the education of the household head as well as the average education of other adult household members the signs on these coefficients switch across these two variables. More rainfall reduces time allocated to the collection of on- and off-farm fuelwood. This is likely because increased rainfall hinders collection and storage of fuelwood.

Table 5: 3SLS Results on the Tradeoffs between Agricultural Productivity and Biomass Collection Times

VARIABLES	(1) Productivity (value of output/ha)	(2) Dung collection time (hrs/yr)	(3) On-farm wood collection time (hrs/yr)	(4) Off-farm wood collection time (hrs/yr)	(5) Residue collection time (hrs/yr)
Labor per ha	0.283				
	(0.308)				
Urea per ha	0.187				
	(0.220)				
DAP per ha	0.225				
	(0.177)				
Oxen per ha	0.163*				
	(0.0950)				
Pesticide per ha	-0.177				
	(0.120)				
Male head	-0.0141	1.029**	-1.093**	-1.061**	-0.906*
	(0.0522)	(0.405)	(0.473)	(0.496)	(0.508)
Head's age	0.000857	-0.00620	-0.00284	-0.00606	0.0173
	(0.00109)	(0.0108)	(0.0127)	(0.0130)	(0.0121)
Head's education	0.00207	-0.221**	0.165	0.167	0.263**
	(0.0113)	(0.108)	(0.125)	(0.128)	(0.122)
Members' years of schooling	0.00173	0.177**	-0.0969	-0.0602	-0.244**
	(0.00758)	(0.0791)	(0.0926)	(0.0982)	(0.0983)
Married	0.0597				
	(0.0385)				
Soil fertility	-0.0564*				
	(0.0329)				
Slope of the plot	0.0159				
	(0.0321)				
Erosion	0.0276				
	(0.0343)				
Days spent on dung collection	-0.0534*		0.932***	0.862***	0.930***
	(0.0304)		(0.175)	(0.221)	(0.198)
Days spent on on-farm fuelwood collection	0.0586***	0.730***		-1.024***	-0.374*
	(0.0202)	(0.126)		(0.129)	(0.213)
Days spent on off-farm fuelwood collection	0.0285*	0.663***	-0.875***		-0.310
	(0.0172)	(0.149)	(0.110)		(0.216)
Days spent on crop residue collection	-0.00263	0.511***	0.0107	0.128	
	(0.0217)	(0.0962)	(0.145)	(0.153)	
Extension	0.0810				
	(0.159)				
Rainfall	0.247*	0.783	-3.167*	-3.452*	1.570
	(0.144)	(1.545)	(1.719)	(1.815)	(1.776)
Elevation	0.0755				
	(0.0963)				

Table 5 continued

VARIABLES	(1) Productivity (value of output/ha)	(2) Dung collection time (hrs/yr)	(3) On-farm wood collection time (hrs/yr)	(4) Off-farm wood collection time (hrs/yr)	(5) Residue collection time (hrs/yr)
Improved varieties used	-0.00166				
	(0.0734)				
Climate smart agricultural practices	-0.0170				
	(0.0127)				
Value of output per ha		-0.624**	0.747**	0.771**	0.465
		(0.299)	(0.315)	(0.334)	(0.393)
Livestock units owned		0.548***			-0.981***
		(0.182)			(0.284)
Charcoal stove		4.640***	-6.024***	-6.238***	-2.608
		(1.424)	(1.445)	(1.595)	(1.833)
Access to electricity		-0.640***	0.508**	0.476**	0.696***
		(0.179)	(0.204)	(0.216)	(0.216)
Number of timber trees		0.328***	-0.364***	-0.379***	-0.240*
		(0.117)	(0.126)	(0.130)	(0.141)
Ratio of adult men		-0.496	0.184	0.200	0.693*
		(0.369)	(0.416)	(0.436)	(0.416)
Household size		-0.0440	-0.0270	-0.0429	0.112**
		(0.0394)	(0.0420)	(0.0432)	(0.0461)
Distance to market		0.00188	-0.00345	-0.00254	0.000110
		(0.00241)	(0.00244)	(0.00276)	(0.00300)
Average temperature		0.000893			
		(0.0249)			
Barley price					-0.0256
					(0.103)
Maize price					0.453
					(0.467)
Teff price					-0.276
					(1.107)
Wheat price					-0.00882
					(0.621)
Constant	-2.060	-3.034	20.17*	22.49*	-13.97
	(1.426)	(11.10)	(12.09)	(12.72)	(12.62)
Observations	785	785	785	785	785
R-squared	-2.088	0.235	-0.169	-0.026	-0.408

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The SUR results are largely supportive of the 3SLS results with some notable exceptions. Without addressing endogeneity bias, the SUR results show a positive relationship between days spent collecting dung and agricultural productivity. In addition, several inputs variables, such as labor and fertilizer, appear to positively affect agricultural productivity. The results are shown in Appendix Table 1.

6. Discussion and Conclusions

The analysis in this paper has some important limitations that are worth noting. First, only a cross section of data which contained the variables in domestic energy collection and use was available. Therefore, the analysis could only consider the production implications of the removal of biomass energy sources from the field during the same season. Rather, the effects on agricultural production are likely to manifest in the season following the biomass removal. However, we are unable to capture these lagged effects. In addition, the collection time variable is not fully gender-disaggregated as the dataset only indicates the primary collector of each fuel source. More details on the time spent by individual household members on energy collection would offer a more detailed picture into the labor tradeoffs involved in biomass energy use.

Despite these limitations, the results show that the removal of dung from the field negatively affects agricultural productivity while both on- and off-farm fuelwood collection increase productivity. In the case of cow dung, removal of this fuel source from the field has negative implications for agricultural productivity due to the loss of soil organic matter. That is, greater time spent collecting dung and residues suggests that more of these materials are being extracted from agricultural plots with negative ramifications for soil fertility and food crop production.

The findings highlight the importance of livestock in any discussion about the tradeoffs between agriculture and domestic energy use. Livestock provide an essential source of energy used for fuel (dung) which appears to be collected more when more is available (as represented by the number of livestock owned by the household). On the other hand, livestock require large energy input (crop residues as feed) and the results show that when households own more livestock, the priority is to use crop residues for feed rather than fuel.

Moreover, the results showed that collection of both on- and off-farm fuelwood is associated with higher agricultural productivity. Similarly, more productive households are more likely to spend more time collecting fuelwood and less time collecting dung. In particular, on-farm fuelwood production is associated with higher agricultural productivity. This supports the idea that agroforestry provides many benefits for crop production including providing shade, improving soil properties and providing labor savings, by making fuelwood collection easier and more convenient for households.

The results also support the notion that rural households rely on multiple sources of fuel. In this study, we consider collection times as a good proxy for quantity of fuel sources used. In general, the results show that when collection times of one fuel source increases collection of alternative fuels also increases. In particular, dung, fuelwood, and crop residues, all of which are used for cooking, appear to be complementary. However, there are some exceptions; namely, on-farm and off-farm fuelwood appear to be substitutes. That is, farmers with access to on-farm fuelwood are less likely to collect it off-farm and vice versa. This suggests that efforts to promote agroforestry would save rural households considerable time collecting fuelwood and also have additional benefits for crop productivity.

At the same time, the results show that rural households in Ethiopia have extremely limited options for their supply of domestic energy. Given that modern fuel sources and technologies are either unavailable or inaccessible for most rural farm households, the vast majority rely on traditional biomass sources of fuel. While use of a charcoal stove is associated with less time spent collecting wood, given that charcoal is a substitute for fuelwood, very few rural households can afford to purchase charcoal. Nor do they have an incentive to switch to charcoal when biomass energy sources are readily collected for free.

While Ethiopia is rapidly increasing access to electricity throughout the country, the results suggest that this will do little to affect biomass energy consumption. Access to electricity does not decrease dependence on fuelwood, as electricity is used for lighting while fuelwood is used for cooking. In the absence of complementary technologies for cooking and heating, such as electric, gas, or even improved wood-burning stoves, as well as alternative, modern fuel sources, such as kerosene, rural households in Ethiopia are likely to continue their reliance on traditional biomass sources of energy.

Agricultural and rural development depend on the ability of smallholder producers to meet their domestic energy needs. This will require the development and dissemination of new, affordable technologies, such as improved cookstoves, which will enable farmers to meet their domestic energy needs while leaving more biomass energy sources available for crop and livestock production and allowing more labor and resources to be devoted to income-earning or agricultural productivity-enhancing activities.

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Appendix Table 1: SUR Results on the Tradeoffs between Agricultural Productivity and Biomass Collection Times

VARIABLES	(1) Productivity (value of output/ha)	(2) Dung collection time (hrs/yr)	(3) On-farm wood collection time (hrs/yr)	(4) Off-farm wood collection time (hrs/yr)	(5) Residue collection time (hrs/yr)
Labor per ha	0.0812***				
	(0.0250)				
Urea per ha	0.0149				
	(0.0126)				
DAP per ha	0.0282*				
	(0.0150)				
Oxen per ha	0.0460***				
	(0.0104)				
Pesticide per ha	0.00291				
	(0.00643)				
Male head	0.00810	0.286*	-0.524**	-0.676***	-0.0387
	(0.0148)	(0.166)	(0.212)	(0.223)	(0.194)
Head's age	0.000451**	-0.000400	-0.00395	-0.0106**	0.00532
	(0.000216)	(0.00378)	(0.00485)	(0.00511)	(0.00438)
Head's education	0.00128	-0.0421***	0.00983	-0.00516	0.0507***
	(0.000903)	(0.0157)	(0.0202)	(0.0213)	(0.0181)
Members' years of schooling	0.000899	0.0135	-0.0288	-0.0234	0.00994
	(0.000930)	(0.0167)	(0.0213)	(0.0226)	(0.0196)
Married	0.00446				
	(0.0143)				
Soil fertility	-0.0202**				
	(0.0102)				
Slope of the plot	0.0131				
	(0.0143)				
Erosion	0.0100				
	(0.0125)				
Days spent on dung collection	0.00390*		0.769***	0.618***	0.127***
	(0.00206)		(0.0401)	(0.0456)	(0.0407)
Days spent on on-farm fuelwood collection	0.0105***	0.466***		-0.808***	0.280***
	(0.00161)	(0.0245)		(0.0310)	(0.0310)
Days spent on off-farm fuelwood collection	0.00944***	0.337***	-0.723***		0.290***
	(0.00152)	(0.0253)	(0.0278)		(0.0300)
Days spent on crop residue collection	-0.00165	0.101***	0.364***	0.417***	
	(0.00176)	(0.0298)	(0.0370)	(0.0391)	
Extension	0.0124				
	(0.0118)				

Appendix Table 1 continued

VARIABLES	(1) Productivity (value of output/ha)	(2) Dung collection time (hrs/yr)	(3) On-farm wood collection time (hrs/yr)	(4) Off-farm wood collection time (hrs/yr)	(5) Residue collection time (hrs/yr)
Rainfall	0.0614	1.776*	-3.684***	-3.845***	0.981
	(0.0529)	(1.072)	(1.177)	(1.244)	(1.231)
Elevation	0.0619**				
	(0.0307)				
Improved varieties used	0.000429				
	(0.00593)				
Climate smart agricultural practices	0.00107				
	(0.00130)				
Value of output per ha		0.167**	0.687***	0.726***	0.0103
		(0.0676)	(0.0850)	(0.0902)	(0.0803)
Livestock units owned		0.0127			-0.194***
		(0.0418)			(0.0512)
Charcoal stove		0.452**	-0.462*	-0.599**	0.0298
		(0.204)	(0.260)	(0.275)	(0.236)
Access to electricity		-0.125	-0.00564	0.0798	0.303**
		(0.102)	(0.130)	(0.137)	(0.118)
Number of timber trees		-0.00296	-0.0313	-0.0435	-0.00948
		(0.0224)	(0.0282)	(0.0299)	(0.0262)
Ratio of adult men		-0.172	0.0546	0.126	0.0341
		(0.255)	(0.325)	(0.344)	(0.295)
Household size		0.0101	-0.0259	-0.0495*	-0.00543
		(0.0207)	(0.0260)	(0.0275)	(0.0242)
Distance to market		0.000712	-0.00187	0.00231	0.00245
		(0.00131)	(0.00165)	(0.00175)	(0.00163)
Average temperature		0.0158			
		(0.0323)			
Barley price					0.00250
					(0.0978)
Maize price					2.324***
					(0.456)
Teff price					0.195
					(1.025)
Wheat price					-0.388
					(0.609)
Constant	-0.295	-12.47	21.84***	23.09***	-11.33
	(0.415)	(7.826)	(7.960)	(8.421)	(8.921)
Observations	786	786	786	786	786
R-squared	0.398	0.724	0.338	0.422	0.392

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1