Household energy demand and environmental management in Kenya
Nyang, F.O.

Citation for published version (APA):

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: http://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.
Chapter 8

Firewood production and consumption in Kenya: an application of the agricultural household model

The analysis in this chapter is concerned with the production and consumption of firewood in rural households that collect rather than purchase firewood. Firewood is a subsistence commodity in such households; and most of them collect only as much as they need for short term use often with a little extra. The mode of transporting firewood in these cases is invariably on the person of the firewood seeker who is usually travelling on foot. Thus the distance to the firewood source, and the effort expended in harvesting the firewood are of critical importance in the analysis. Some of the firewood may be collected on the households farm, hence it stands to reason that farm size may be a determinant of the amount of firewood harvested. The two fuel mixes that are mainly used by such households are either kerosene+firewood or kerosene+charcoal+firewood. These are the two mixes used in the estimation of the consumption side of the model. The first part of this chapter sketches the background and theory of agricultural household models. The latter parts of the chapter are devoted to the empirical estimation of a static, recursive agricultural household model and the determination of the shadow price of firewood among buyers and collectors. In either case the analysis is restricted to households that transport firewood on foot. The discussion in the previous chapter indicated that firewood scarcity profiles for the two modes of transportation tend to be different, hence the need to distinguish between them. The decision to analyse households that transport firewood by foot is mainly motivated by the fact that the majority of the households in rural areas use this method. However,
it is also motivated by some fundamental differences in the characteristics of the households in either group, such as: the differences in the productivity of household labour due to the two modes of transporting firewood; the differences in the type of labour employed; the differences in household profiles between the two groups in terms of income, occupation, and farm sizes. Households using motorised transport tend to use hired labour, whereas those transporting firewood on foot basically use family labour - mainly the labour of women and children. Households using motorised transport also tend to be better-off and most often the heads of such households are engaged in the occupation categorised as both farming and non-farming.

8.1 The theoretical framework of agricultural household models

Chayanov (1926) is generally regarded as the initiator of agricultural household models (also known as household-firm models). Currently, an extensive literature exists on the subject. See, for instance: Krishna (1969), Sen (1966), Nakajima (1969), Jorgenson and Lau (1969), Barnum and Squire (1979), and Lopez (1984), to mention some frequently cited works. Agricultural household models (AHM’s) are microeconomic models of farm households that combine producer, consumer, and labour supply decisions in a theoretically consistent manner. They are therefore particularly useful for goods that are both produced and consumed by the household, such as firewood. The core of the analysis in agricultural household models involves the allocation of household time between the production of home produced goods (the so called Z goods); and wage work. Production of Z goods requires inputs of household time as well as purchased commodities. The household therefore plays a dual role: in production the household combines labour, land and capital to produce the good, say firewood; in consumption firewood is one of the arguments in the household’s utility function.

Agricultural household models maximise a utility function subject to three constraints: a production function, a time (or labour supply) constraint, and a budget constraint. In the absence of markets a subsistence model is assumed, for instance see Nakajima (1969); Sen (1966). Benjamin (1992) also reports Chayanov (1926) as observing that when there is no labour market the farms’ labour input depends on family composition. Demographic variables therefore play an important role in non-separating agricultural household models. For examples of non-separating agricultural household models see Lopez (1984, 1986) and Amacher, Hyde, Kanel (1996).

Where markets do exist: that is where households produce and consume goods and buy or sell the difference, a semi-subsistence model is assumed; for instance see Strauss (1983).
Household-firm models have been extended to accommodate possibilities such as intra-household distribution, for instance see Jorgenson and Lau (1969); and the incorporation of demographic variables, see Strauss (1983). Critics of agricultural household models such as Koopman (1992), however, dismiss the plausibility of the results of agricultural household models in African agricultural households and hence of the relevance of the policy conclusions made thereof. However, the awareness of the weaknesses of these models, is in its self a strong point in so far as it delineates the relevance of policy prescriptions from these models.

By definition, semi-subsistence household-firm models are recursive or separable. It is this property which allows for separate specification and estimation of the consumer and producer sides of the model. In essence the household behaves as if its production decisions are made first and then used in allocating potential full income between the consumption of goods and of leisure. The separability property fundamentally rests on the existence of markets for goods and labour and on perfect substitution between hired and family labour (Strauss, 1983). As Benjamin (1992; p. 287) puts it:

"... The most important implication [of separation] is that when markets are complete and efficient, market prices support a separation of household consumption and production decisions."

Benjamin’s objective was to test for separation using the observation that in the absence of labour markets, household composition is an important determinant of labour use. He was, however, unable to reject the null hypothesis that farm labour allocation decisions are independent of household structure.

### 8.1.1 Dynamic agricultural household models

The example of dynamic agricultural household models discussed in this section is based on Wiedenmann (1991). Some aspects of this example have already been introduced in section 1.2 and may also be found in Larson and Bromley (1990) where the model is used to analyse household incentives for resource use under private and common property. See also Binkley (1987). No attempt is made to estimate a dynamic agricultural household model in this thesis due to lack of appropriate data. However, the example of a dynamic agricultural household model is discussed here briefly because it describes the situation of rural households and their relationship to the environment more accurately than is possible with a static model, which only gives a snapshot of the situation at a given point in time. The article by Wiedenmann is particularly relevant because its formulation includes afforestation activities and firewood stove capital costs. It is therefore possible to infer the role that these two variables play in the dynamics of the household-firm model. The on-farm tree density variable which has already been introduced in
Chapter 3 and discussed in Chapter 7, is related to a households afforestation activities; and is a crude measure of the stocks of wood owned by the household. It is thus one of the households' environmental management variables; and is further analysed in Chapter 9. The stove capital referred to in Wiedenmann (1991) could well be the stock of improved woodfuel stoves: the Kenya ceramic \textit{jiko} and the \textit{maendeleo jiko} already discussed in Chapter 4 and in Chapter 5. The role played by these stoves in the households demand for energy is one of the core issues analysed in this thesis.

Both Binkley (1987) and Wiedenmann (1991) concede that the empirical implementation of the solutions from dynamic agricultural household models is difficult. For instance, Wiedenmann notes that one of the principal difficulties is the choice of a shadow price for firewood. The shadow price has important implications in the firewood economy: if firewood users are charged the optimal shadow price, investments in firewood stoves can be left to private decisions since stove investment decisions will be formed according to the dictates of the market. In addition firewood resources will be exploited at an optimal rate; waste will be minimised, and producers encouraged to invest in firewood production. The determination of the shadow price of firewood is thus a critical issue in energy economics, and especially in developing countries such as Kenya where firewood provides most of the energy used by households. The example of the dynamic model discussed serves as an illustration of the importance of the dynamic nature of the shadow price of firewood. As stated earlier this study does not estimate a dynamic agricultural household model due to lack of appropriate data. However, in the next section a static agricultural household model is estimated; and from the model the shadow price of firewood in Kenya (1995) is determined.

8.1.2 Static agricultural household models

The market is a critical part of separable agricultural household models. Following Strauss (1986), Benjamin (1992), and Amacher, Hyde and Kanel (1996); the specification of a separable agricultural household model in this thesis proceeds on the assumption that all prices are exogenous. A household utility function is assumed to exist; it is twice differentiable and quasi-concave and is defined over the consumption of other goods, $X$, firewood, $q_w$, and leisure, $l$ given demographic variables $a$. Firewood is an intermediate input in the household utility function; but a direct input into the households consumption, $C$ of goods and services requiring firewood inputs: $C(q_w, K)$, where $K$ is stove capital.

The households utility function is

$$U = U(X, C(q_w, K), l; a)$$
It maximises this utility subject to a twice differentiable concave production function for firewood

\[ Q_{col1} = Q(L; V; A) \]

Where

- \( L \) = Total labour supply, which may be the sum of family and hired labour where the price of hired labour and off-farm labour is \( \omega \).
- \( V \) = Non-labour variable inputs.
- \( A \) = Land, which is assumed fixed and exogenous.

The household has a time endowment \( T(a) \) and an exogenous income \( E \). Household time is allocated between leisure and work; where work may be on or off-farm. Labour can also be purchased to produce firewood which can be sold at a price \( p_w \) in a competitive market.

The household's problem is:

\[
\max_{X, C, K, L, V} U(X, C(q_w, K), L; a) \]

subject to: (i) \[ xp_x + p_w q_w + \omega L = E + P_w Q_{col1} (L, V; A) - \omega L - \sum p_i V_i \]

(ii) \[ L + L = T(a) \]

The budget and time constraint can be combined into a single constraint so that consumption plus leisure equals full income \( M \); which is composed of exogenous income, the value of time endowment, and non-maximised profits from firewood sales

\[ M = xp_x + p_w q_w + \omega L = E + \omega T(a) + \pi (p_w, \omega; A) \]

If the utility function is maximised subject to fixed (by assumption) full income one of the first order conditions obtained after simplification is:

\[
\omega - p_w \frac{\partial Q_c}{\partial L} = 0 \quad (8.1)
\]

This result contains the endogenous variable, \( L \), and hence can be solved for labour as a function of prices and the technological parameters of the production function, and the fixed area. The production decision is thus made independently of labour supply and consumption decisions - this is the separation property referred to earlier on. The household's optimal choice of labour: \( L^* = L^*(\omega, p_w; A) \) depends only on prices and the production technology. The preferences of the household have no influence upon the optimal choice of labour.

If the optimal choice of labour is substituted into the full income equation the full income associated with profit maximisation \( (M^*) \), is obtained. In principle an indirect utility function
$U = f(M^*, p, w, a)$ can be obtained by maximising the original utility function subject to the profit maximising value of full income $M^*$. The first order conditions yield Marshallian demand equations for leisure, labour, and firewood.

As Benjamin (1992) points out the results of the recursive agricultural household models are sensitive to the violation of its basic assumptions. Violation of one or more of the assumptions renders the model non-separable. The absence of labour markets is one phenomenon that renders the model non-separable. Jacoby (1988), Chayanov (1926), Nakajima (1968), and Sen (1966) all stress the importance of household size as a determinant of the "subjective equilibrium" for agricultural households. Benjamin (1992; p. 290) lists other sensitive assumptions as:

(a) Households have preferences for working on their farms;
(b) Family and hired labour are not perfect substitutes in production;
(c) Some markets are incomplete; for instance if off-farm employment opportunities are limited, the household’s on and off-farm labour decisions will not be separable. As an example; the markets for firewood are poorly developed.
(d) Consumption behaviour is not independent of production behaviour because income is determined by the households production activities hence factors influencing production, affect $M^*$, and ultimately the consumption behaviour.

In practice, researchers often take advantage of the recursive property to estimate the production and consumption sides of agricultural household models separately, see Barnum and Squire (1979) or Strauss (1983). A notable exception is Amacher et al, (1996) who estimate a non-separable agricultural household model of firewood production and consumption. In the following section, the recursive property discussed in sub-section 8.1.2 is invoked to estimate a recursive model of firewood production and consumption in rural Kenya.

### 8.2 A recursive model of firewood production and consumption in rural Kenya

As mentioned in sub-section 8.1.2 above, the recursive property in agricultural household models makes it possible for the production and consumption sides of the model to be estimated separately. From Equation 8.1 it is apparent that the households optimal choice of labour depends only on prices and production technology. For the production side of this model a Cobb-Douglas technology incorporating land and labour is specified. The model is adjusted for household size and for the distances that households members walk in search of firewood. This model therefore applies to those households that use family labour in the collection of firewood, and transport the
firewood thus collected on their backs, shoulders or heads. The model, which is estimated in the double logarithmic format, is presented in Equation 8.1 below.

$$\ln Q_{col} = \beta_0 + \beta_F \ln Fsz + \beta_L \ln HHhrs + \beta_H \ln HHsz + \beta_D \ln Dst + \nu$$

(8.2)

Where

- $\beta_0, \beta_F, \beta_L, \beta_H, \beta_D$ are parameters to be estimated.
- $Q_{col}$ is the quantity of firewood (kg) collected by the household in one month; and is the output in this production process.
- $HHhrs$ is the number of hours spent by the household in collecting one month's supply of firewood. It is the measure of labour input into this production process. It is anticipated that the quantity collected should be an increasing function of the labour input. The coefficient for labour ($\beta_L$) should therefore be positive and less than unity. As explained in Chapter 7 this variable refers to the number of hours spent by the group of persons from a given household in collecting firewood. There is no data on the actual number and composition of the persons in the group.
- $Fsz$ is the size of the farm (acres) owned by the household. The analysis in Chapter 3, indicated that the on-farm tree density is higher in smaller farms, thus smaller farms may also have a higher per unit firewood output; provided firewood output is correlated with on-farm tree density. Furthermore, it is also anticipated that households with smaller farms should have a higher firewood output because such farms tend to be in the more productive high altitude zones. The coefficient for farm size ($\beta_F$) should therefore be negative and less than unity.
- $Hhsz$ is the number of persons in the household. This variable is included to correct for the effect of household size on the output of firewood; since larger households tend to collect correspondingly larger quantities of firewood. The coefficient for household size ($\beta_H$) should therefore be positive and less than unity.
- $Dst$ is the distance travelled by household members in search of firewood. This variable is included to correct for the physical limitation of a human being's ability to carry a given load over a distance. The longer the distance the more difficult it is to carry a given load of firewood. Thus firewood output should be a decreasing function of the distance over which the household members need to carry it. Hence the coefficient for distance ($\beta_D$) should be negative and less than unity.
The parameter estimates for the model in Equation 8.2 are presented in Table 8.1. Four out of the five coefficients are statistically significant in the unrestricted model, and also bear the anticipated signs. However, the model explains less than half of the variation in firewood output. The negative sign on the coefficient for distance travelled indicates that firewood output declines with increasing distance to the source: the farther the source, the lower the firewood output ceteris paribus. Farm size turns out to be statistically insignificant in firewood production; but the labour input is significant as is the household size.

Table 8.1: Parameter estimates of the production side of a separable agricultural household model for firewood production and consumption.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_p$</td>
<td>3.9390</td>
</tr>
<tr>
<td></td>
<td>(26.504)**</td>
</tr>
<tr>
<td>$\beta_L$</td>
<td>0.3213</td>
</tr>
<tr>
<td></td>
<td>(9.621)**</td>
</tr>
<tr>
<td>$\beta_F$</td>
<td>-0.0100</td>
</tr>
<tr>
<td></td>
<td>(-0.574)</td>
</tr>
<tr>
<td>$\beta_H$</td>
<td>0.3393</td>
</tr>
<tr>
<td></td>
<td>(5.611)**</td>
</tr>
<tr>
<td>$\beta_D$</td>
<td>-0.0649</td>
</tr>
<tr>
<td></td>
<td>(-4.466)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.3517</td>
</tr>
<tr>
<td>$n$</td>
<td>300</td>
</tr>
</tbody>
</table>

The figures in parentheses are t-statistics for the null hypothesis that the respective coefficient is zero.

* Significant at 10%  ** Significant at 5%  *** Significant at 1%

Source: estimates from own survey 1995
Under competitive conditions, a profit maximising condition for firewood production is that the value of the marginal product of labour \((VMP_L)\) in firewood production should equal the price of the labour input \((\omega)\). This is the condition which yields the shadow price of firewood and may be derived from the first order condition in Equation 8.1 which is reproduced below as Equation 8.1a

\[
\omega - p_v \frac{\partial Q_c(.)}{\partial L} = 0 \\
\omega - p_v \cdot MP_L = 0 \\
\Rightarrow \omega = VMP_L
\]  

(8.1a)

The marginal product of household labour in firewood production can be computed from the mean value of the quantity of firewood collected, the mean household hours expended, and the coefficient \(\beta_L\) from Equation 8.2, the value of which is given in Table 8.1. Thus the shadow price of collected firewood can be computed from Equation 8.3 using wage and firewood price data in conjunction with the marginal product of family labour in firewood production.

\[
P_{sw} = \frac{\omega \cdot HHhrs}{Q_{coll} \cdot \beta_L} \quad (8.3)
\]

This is the expression used in computing the shadow price of firewood for households in rural Kenya, the results of which are presented in Table 8.2 below.

In 1995, the official urban wage in Kenya was KSh 70.00 for an eight hour day. The official wage was lower in rural areas and ranged from KSh 50.00 in the agriculturally more productive tea and coffee growing zones, to as low as KSh 20.00 in the semi arid regions. Using these wages the shadow prices of firewood, both for households that used collected firewood and those that used purchased firewood, were computed using Equation 8.3 as explained in the previous paragraph. The mean and median shadow prices computed in this manner are presented in Table 8.2; and illustrated in Figure 8.1. Since the marginal product of labour is based on household hours the wage rate may be interpreted as being the wage for the group that goes to collect firewood. For instance, if the group consists of a mother and two children, the children’s labour may count for nothing.
### Table 8.2: The mean observed prices of firewood and the mean shadow prices for collectors and buyers of firewood in Kenya (1995).

<table>
<thead>
<tr>
<th>Wages (KSh/day)</th>
<th>RURAL 20.00</th>
<th>RURAL 30.00</th>
<th>RURAL 40.00</th>
<th>RURAL 50.00</th>
<th>URBAN 70.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed price</td>
<td>0.77</td>
<td>0.59</td>
<td>1.02</td>
<td>1.02</td>
<td>0.97</td>
</tr>
<tr>
<td>(0.64)</td>
<td>(0.60)</td>
<td>(0.63)</td>
<td>(0.83)</td>
<td>(0.70)</td>
<td></td>
</tr>
<tr>
<td>Shadow price collectors</td>
<td>0.53</td>
<td>0.85</td>
<td>1.12</td>
<td>1.16</td>
<td>2.66</td>
</tr>
<tr>
<td>(0.39)</td>
<td>(0.78)</td>
<td>(1.04)</td>
<td>(1.01)</td>
<td>(2.22)</td>
<td></td>
</tr>
<tr>
<td>Shadow price buyers</td>
<td>1.16</td>
<td>1.25</td>
<td>1.23</td>
<td>1.92</td>
<td>2.16</td>
</tr>
<tr>
<td>(0.91)</td>
<td>(1.12)</td>
<td>(0.78)</td>
<td>(1.56)</td>
<td>(2.26)</td>
<td></td>
</tr>
</tbody>
</table>

The figures in parentheses are the median values

*Based on the assumption that the buyers spent the time collecting rather than buying firewood.

Source: estimates from own survey 1995

From Figure 8.1, it is clear that the shadow prices are generally higher than the observed firewood prices; with the differences between the observed and shadow prices being much larger at higher wages such as those prevailing in urban centers. However, at the lowest wages the shadow price of collected firewood is actually less than the observed price of firewood. The shadow price of firewood among buyer-households exceeds the observed price at all wages, thus indicating that firewood is under-priced at all the wages, but more so at higher wages. The observed price is in some cases a mere 45% of the shadow price among buyer-households and 35% among collector-households; thus giving a general indication of the extent to which firewood is under-priced in rural Kenya.
The shadow price of firewood among buyer-households and the observed prices form an upper and lower bound respectively within which the shadow price among collector-households lies except at the extreme wages. At the very low wages the shadow price of firewood among collector-households is lower than both the observed price and the shadow price among buyer-households. At the urban wage of KSh 70.00 the shadow price among collector-households lies above both the observed price and the shadow price among buyer-households. Thus at the very low wage rates it is cheaper for households to collect firewood rather than purchase it. For instance at a wage rate of KSh 20.00 the shadow price of collected firewood is approximately $\frac{3}{5}$ of the observed price. Thus households collecting firewood save up to $\frac{3}{5}$ on the observed price.

**Figure 8.1:** Observed firewood prices and shadow prices for collected and purchased firewood in Kenya in 1995.
However, this saving diminishes fairly fast as the wage rate increases. At a wage rate of KSh 30.00 it has vanished and become an opportunity cost which grows as rural wage rates approach urban wages.

As was noted earlier, rural wages are lowest in arid and semi-arid parts of Kenya and tend to be higher in the agriculturally more productive parts of the country. Thus from the preceding paragraphs it is apparent that households in the arid and semi-arid parts of Kenya should find it cheaper to collect firewood than to purchase it. This may be applicable in areas such as Kitui district, lower Baringo and Embu, as well as the rangelands in Laikipia district. By the same token, the indication is that households in the agriculturally more productive areas where the wages are closer to the urban wages should find it cheaper to purchase rather than collect firewood. The upshot of this argument in the case of the latter group is that there exists an opportunity for households to specialise in the commercial production of firewood in these zones. Indeed as will be argued in Chapter 9, households residing in higher altitude zones are more likely to purchase firewood than those at the lower altitudes. It will also be argued in Chapter 9 that the on-farm tree density tends to be higher and the farm sizes smaller at higher altitudes. Both these arguments support the notion of the collector-households at higher altitudes experiencing a higher shadow price for collected firewood than for purchased firewood; and hence being compelled to purchase rather than collect firewood.

The consumption side is modelled with the LAAIDS; the specification of which has been discussed in Chapter 5. The OLS parameter estimates for the non-homothetic model are presented in Table 8.3 for the two fuel mixes kerosene+firewood and kerosene+charcoal+firewood; which are the mixes predominantly used by collector-households. The results indicate that collected firewood is approximately unit price elastic and income elastic in both fuel mixes. The cross-price elasticities indicate that firewood is a substitute for kerosene and a complement for charcoal in the kerosene+charcoal+firewood fuel mix.

The economic variables perform well except for the price of charcoal which is insignificant in all the regressions. The shadow price of firewood performs particularly well; and so does the imputed expenditure. Demographic and environmental variables perform rather poorly with the Kerosene+charcoal+firewood fuel mix, and hence were excluded from the final model. However, in the Kerosene+firewood fuel mix household size and occupation; as well as the mean altitude do perform well. In this mix the imputed share of firewood is a decreasing function of household size, thus implying that the influence of the public good uses of firewood play an important role in the demand for firewood. The co-efficient for the dummy variable indicating that the household head is engaged in both farming and non-farming occupations is also significant for the latter fuel mix. Its negative sign indicates that households with heads in this
Table 8.3: Non-homothetic OLS parameter estimates for the consumption side of a separable agricultural household model for firewood production and consumption.

<table>
<thead>
<tr>
<th></th>
<th>Kerosene+charcoal+firewood</th>
<th>Kerosene+firewood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( n=114 )</td>
<td>( n=232 )</td>
</tr>
<tr>
<td>( \alpha_i )</td>
<td>1.0154 (5.320)**</td>
<td>1.1870 (12.674)**</td>
</tr>
<tr>
<td>( \beta_{ik} )</td>
<td>-0.1561 (-9.587)**</td>
<td>-0.1626 (-19.249)**</td>
</tr>
<tr>
<td>( \gamma_{ik} )</td>
<td>0.0189 (0.372)</td>
<td>-0.1870 (12.674)**</td>
</tr>
<tr>
<td>( \gamma_{ic} )</td>
<td>-0.0268 (-1.338)</td>
<td>-0.1626 (-19.249)**</td>
</tr>
<tr>
<td>( \gamma_{iw} )</td>
<td>-0.0462 (-3.406)**</td>
<td>-0.0854 (-9.807)**</td>
</tr>
<tr>
<td>( \lambda_{DMj} )</td>
<td>0.0324 (1.686)**</td>
<td>0.0354 (2.210)**</td>
</tr>
<tr>
<td>( \lambda_{DKj} )</td>
<td>0.0232 (1.291)**</td>
<td>-0.0767 (6.554)**</td>
</tr>
<tr>
<td>( \lambda_{HZ} )</td>
<td>-0.0161 (-0.346)</td>
<td>-0.0767 (6.554)**</td>
</tr>
<tr>
<td>( \lambda_{ocnj} )</td>
<td>-0.0750 (1.933)**</td>
<td>-0.0176 (1.679)**</td>
</tr>
<tr>
<td>( \lambda_{ocnj+f} )</td>
<td>-0.0071 (-0.346)</td>
<td>-0.0235 (0.919)</td>
</tr>
<tr>
<td>( \lambda_{alt} )</td>
<td>-0.0767 (6.554)**</td>
<td>-0.0176 (1.679)**</td>
</tr>
</tbody>
</table>

Notes:
- \(*\) denotes significance at the 10% level.
- \(**\) denotes significance at the 5% level.
- \(**\) denotes significance at the 1% level.
**Chapter 8: An application of the agricultural household model**

<table>
<thead>
<tr>
<th>$\bar{w}_j$</th>
<th>0.268</th>
<th>0.232</th>
<th>0.500</th>
<th>0.302</th>
<th>0.698</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$</td>
<td>0.7046</td>
<td>-</td>
<td>0.7732</td>
<td>0.8183</td>
<td>-</td>
</tr>
<tr>
<td>$\bar{R}^2$</td>
<td>0.6880</td>
<td>-</td>
<td>0.7605</td>
<td>0.8117</td>
<td>-</td>
</tr>
<tr>
<td>DW</td>
<td>1.9144</td>
<td>-</td>
<td>2.0612</td>
<td>1.7884</td>
<td>-</td>
</tr>
</tbody>
</table>

**Expenditure and price elasticities**

<table>
<thead>
<tr>
<th>$e_{ix}$</th>
<th>0.4175</th>
<th>0.8853</th>
<th>1.3654</th>
<th>0.4616</th>
<th>1.2330</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_{ik}$</td>
<td>-0.7734</td>
<td>0.9225</td>
<td>0.2781</td>
<td>-1.3546</td>
<td>-0.1211</td>
</tr>
<tr>
<td>$e_{ic}$</td>
<td>0.0351</td>
<td>-0.7415</td>
<td>-0.1388</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$e_{iv}$</td>
<td>0.1188</td>
<td>-0.1862</td>
<td>-0.9773</td>
<td>0.0930</td>
<td>-1.0403</td>
</tr>
</tbody>
</table>

Figures in parentheses are t-statistics for the null hypothesis that the respective coefficient is zero. The price elasticities are uncompensated elasticities.

- Significant at 10%
- Significant at 5%
- Significant at 1%

Source: estimates from own survey 1995
occupational category devote a smaller share of the imputed energy budget to collected firewood. The co-efficient for the dummy variable indicating that the household head is engaged exclusively in a non-farming occupation turns out to be statistically insignificant. This is as anticipated, since such household heads tend to be in professions that pay modest salaries, such as the teaching profession, low cadre medical staff, and junior civil servants. Households in this kind of a set-up basically integrate rather closely with the rural communities in which they live, hence the statistical insignificance of the variable under consideration.

The only environmental variable that turned out to be significant is the mean altitude; and only for the kerosene+firewood fuel mix. The negative sign on its co-efficient indicates that the imputed share of firewood is a decreasing function of the altitude, thus implying that the demand for collected firewood declines with altitude. This concurs with the findings above: that the shadow price among collector-households exceeds the shadow price among buyer-households as the rural wage approaches the urban wage which tends to be at the higher altitudes. For households in the higher altitudes it should therefore be cheaper to use purchased firewood than to use collected firewood. This should be the case in districts like Uasin Gishu and Kakamega, as well as in the higher parts of Embu, Homa Bay, and Baringo.

The use of improved stoves is significant in both fuel mixes but only for the maendeleo jiko which is the firewood burning stove. However, the signs of the coefficient are different for firewood in the two fuel mixes. In the kerosene+charcoal+firewood mix it is positive indicating that for households using this mix, those using the maendeleo jiko devote a bigger share of their imputed energy budget to collected firewood than the non-users of the stove. For households using the kerosene+firewood fuel mix, those using the maendeleo jiko devote a smaller share of their imputed energy budget to collected firewood. Thus the firewood saving effects of the maendeleo jiko should be most evident amongst the households using the kerosene+firewood fuel mix. It is essential to note that in this analysis the firewood saving effects of the improved stoves is being compared between users and non-users of the stoves. Other comparisons are possible as well. For instance, one may be interested in performing a comparative analysis for a given household to ascertain whether the adoption of the improved stove does result in firewood savings. The framework of analysis would then involve "before-adoption" and "after-adoption" scenarios. This kind of analysis is not within the scope of this thesis, and hence is not pursued beyond this note. The effect of the improved charcoal burning stove: the Kenya ceramic jiko is not statistically significant for collector-households using the Kerosene+charcoal+firewood fuel mix.
Chapter 8: APPENDIX

A8.1 A dynamic agricultural household model

Wiedenmann (1991) conducts a total welfare analysis for an agricultural community using a social welfare function. The analysis is based on two assumptions:

(a) The provision of food and heat for cooking are the main parts of total consumption in poor rural areas.

(b) Firewood stove capital can be bought on the urban market at a fixed price in terms of food; hence firewood stove capital can be normalised in terms of food so that a unit of firewood stove capital is equivalent to a unit of food (ibid; p. 83).

The resources involved in the analysis are:

(a) A fixed amount of labour \( \bar{E} \) to be allocated between the following activities:
   - \( L_w \): fuelwood cutting and transportation
   - \( L_y \): agricultural production
   - \( L_a \): afforestation activities

(b) The stock (\( S \)) of the renewable resource of firewood.

(c) Fuelwood stove capital (\( K \)).

The objective of the analysis is to model the supply of heat, \( h \), with a household production function; where the utility integral to be maximised includes food consumption, \( C \), and heat, \( h \). See Wiedenmann (1991; p. 84)

\[
\max_0^\infty \int [U(C(t), h(t)) e^{-\beta t} ] dt
\]  

(A8.1)

subject to:

(i) production functions:
   - Agricultural output: \( Y = Y(L_y, S) \)
   - Firewood output: \( q_w = q_w(L_w) \)
   - Heat output: \( h = h(q_w, K) \)

(ii) Labour supply: \( \bar{E} = L_w + L_y + L_a \)
(iii) Growth functions for:

- Firewood stocks:
  \[ \dot{S} = N(S) + A(L) - q_w(L) \]

- Firewood stove capital:
  \[ \dot{K} = Y - C \]

Where \( \dot{S}, \dot{K} \) are the respective firewood stock and stove capital growth rates.

\( N(S) \) is the natural growth function of the forest which is dependent upon the stock.

The resulting Hamiltonian function is:

\[
H = U(C, h(q_w(L), K)) e^{-\lambda t} + \gamma [\dot{L} - L - L_y - L_t] + \mu [Y(L_y, S) - C]
\]

From an interpretation of the first order conditions for the inner solutions, the following two conclusions are directly applicable to the analysis in this chapter:

(i) The marginal utility of firewood is identical to the private marginal costs of firewood collection plus the shadow price of firewood.

(ii) The marginal costs of afforestation are identical to the dynamic price of fuelwood.

According to Wiedenmann, there are only four paths that approach the steady state in the solution to this dynamic system: When

(a) both capital and tree stocks are either above or below their steady state values.

(b) either capital stock is above but tree stock is below; or capital stock is below and tree stock is above the respective steady state values.