Supply and demand for wood as a source of energy in Zambia: an econometric analysis

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Supply and demand for wood as a source of energy in Zambia: An econometric analysis

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Iowa State University, 1993
Supply and demand for wood as a source of energy in Zambia: An econometric analysis

by

Christopher Mupimpila

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CHAPTER 1. INTRODUCTION

The use of wood for energy in developing countries continues to attract a great deal of attention. The main reason for this is the concern that the majority of the population in developing countries face acute shortages of biomass energy because of the combined effects of increasing demand and diminishing supplies of this source of energy. Zambia is a typical developing country that relies heavily on woodfuel for energy.

Besides, the Zambian economy has, since 1974, experienced a deep and prolonged recession which has lasted for over two decades now. The recession has been attributed to three principal factors (Republic of Zambia, 1989). First, since 1974, there has been a sharp and prolonged fall in the price of copper on the world market, a fall of over 60% in real terms since 1974. In turn, the fall in the world price of copper has been the result of sluggish economic growth in the industrialized countries that import Zambian copper. Second, the recession in Zambia has been aggravated by a continuous fall in export volume and copper production, over 30% drop in output since 1974. The fall in output, in turn, is considered to be the result of decreasing accessibility and richness of Zambian copper deposits. Third, the recession has been aggravated by government economic policies. These policies consisted mainly of price and interest rate controls, and overvalued exchange rate. On the one hand, price controls favored urban consumers at the expense of farmers. This discouraged agricultural production and contributed to
growth in food imports. On the other hand, interest rate controls encouraged the development of capital-intensive production while an overvalued exchange rate prevented the growth of exports.

Thus, the deep and prolonged recession in Zambia is the result of a persistent decline in the price of copper, a fall in copper output, and government economic policies which discourage growth in other sectors of the economy.

The Zambian government initially perceived the recession to be a temporary slump, and therefore, responded to the crisis by increasing external borrowing. However, when the crisis continued and deepened, the government began to emphasize "growth from own resources" (Republic of Zambia, 1989). Starting in the mid-1980s, the government instituted measures aimed at restructuring the economy. The measures include: deregulation of market structures; decontrol of prices, including the price of foreign exchange; restructuring public enterprises, and diversifying the economy away from copper into agriculture and manufacturing.

However, it is the energy sector which holds the best promise to fulfill the dictum, "growth from own resources." This is because Zambia is well endowed with energy resources. Zambian woodlands and forests are estimated to cover 58 million hectares or 77% of the total land area (Republic of Zambia, 1989). The woodlands are estimated to have a growing stock of about 4.3 billion tons of wood (69,000 PJ), giving an annual production of about 130 million tons (2,080 PJ). Zambia's hydropower potential is also estimated at 4,000 MW (84 PJ per year), while coal reserves are over 30 million tons (768 PJ). Thus, Zambia has
adequate domestic energy resources and needs only to import petroleum products.

On the supply side, woodfuel (firewood and charcoal) is estimated to contribute the largest share of the supply of energy in Zambia, it accounts for 64% of total energy supply. The other sources of energy are: electricity, 12%; coal, 7%; petroleum, 11%; and crop residues, 6%. Thus, indigenous energy sources account for 88% of Zambia's total energy use, the remaining 12% is supplied by imported petroleum products; and of all the sources, woodfuel is by far the principal source of energy in Zambia (Republic of Zambia, 1989).

On the demand side, households account for the largest share of demand for energy in Zambia, accounting for 58% of total energy demand (Republic of Zambia, 1989). The other sources of demand are: mining, 18%; industry, 12%; agriculture, government, transport and others, 12%. Households by far account for the largest share of woodfuel demand in Zambia: 84% of total woodfuel demand. The other sources of energy for households are: crop residuals, 12%; electricity, 2%; and kerosene, 2%.

Clearly, the energy sector has invaluable potential to help fulfill the basic aims of development in Zambia, and within the energy sector, wood is by far the principal source of energy in Zambia. This is the reason the present study focuses on wood as a source of energy.

This study consists of seven chapters including the introduction. Chapter II briefly surveys the literature on the supply and demand for wood as a source of energy. From the survey of existing literature, the present study tests two principal hypotheses in the context of Zambia.
First, that demand for woodfuel is a function of income, the price of woodfuel, the prices of alternative fuels, population, inflation, and other factors such as investment and changes in the structure of the economy. Second, that large quantities of woodfuel cannot be supplied through natural tree growth and regeneration, therefore it is necessary to implement a program of woodfuel production from tree plantations and agroforestry systems.

Chapter III sets the theoretical framework of the present study and defines the concepts "demand" and "supply." Chapter IV outlines the model used in this study to test the hypothesis on the demand for woodfuel. The results of the empirical estimation of the wood energy model are discussed in Chapter V. Chapter VI evaluates the supply of wood energy in Zambia while Chapter VII summarizes and draws conclusions from the present study.
CHAPTER II. LITERATURE REVIEW

Background

Studies on supply and demand for energy have for the most part focused on commercial or conventional sources of energy, such as electricity, natural gas, and fuel oil. These studies have also received frequent and detailed reviews, for instance, Hartman (1979) and Bohi and Zimmerman (1984).

On the other hand, energy studies have tended to overlook traditional sources of energy such as firewood and charcoal. The main reason for this is the lack of data on traditional sources of energy. In many countries, good estimates of wood energy are rare since these data do not enter national statistics. In countries where field surveys have been undertaken, researchers have had to contend with the fact that firewood is not homogeneous, and therefore the energy value associated with it varies considerably depending on the species and the moisture content of the wood (Mwandosya and Luhomga, 1985). Researchers have had to overcome difficulties of measurement due to variations in the quality of wood by species, variation in moisture content, and the problems of measuring the various bundles or sticks in which wood is usually collected (Morgan and Moss, 1981).

However, despite the difficulties involved, significant research has been conducted on wood energy in several countries. Studies which are noteworthy include the one by Hewett et al. (1981) on wood energy in the United States of America. The authors begin by stating that: "wood is
humanity's oldest energy resource. It was the fuel that sustained America's early development, and now after a century of decline, it is showing a sharp upswing in popularity" (Hewett et al., 1981, p. 139). According to Hewett et al. (1981), the main reason for the recent rapid rise in wood energy use in the United States is the rapidly rising fuel oil prices since 1974. This view is also shared by Garbacz (1985). In his study on residential demand for fuelwood in the United States, Garbacz cites U. S. Department of Energy Statistics and states that, "... there was a precipitous decline in the U. S. residential fuelwood use from about 61.3 million short tons in 1949 to about 20.6 million short tons in 1973, followed by a sharp rise to 48.2 million in 1981" (Garbacz, 1985, p. 191). The point is simply that even in the context of developed countries, wood can be a significant source of energy and therefore efforts have been made to study this source of energy.

However, it is in developing countries that wood as a source of energy has increasingly attracted a great deal of attention, following the 1973 oil crisis. In developing countries, traditional biomass fuels--firewood, charcoal, crop residuals, and cow dung--are the primary cooking and heating fuels for the vast majority of the population, especially the rural and urban poor. Therefore, several studies have been undertaken to examine the supply and demand for wood as a source of energy in developing countries. The studies which are noteworthy include the one by Morgan and Moss (1981), on woodfuel and rural energy supply in the humid tropics. The authors use tropical Africa and Southeast Asia as a case study.
A theme which runs through much of the study by Morgan and Moss (1981) is that in tropical areas, natural forests provide good timber, but are an inefficient source of woodfuel. Morgan and Moss suggest that reliance on natural regeneration and self-propagated forests is not a viable option for the provision of woodfuel in most areas of tropical Africa and Asia. This, the authors argue, "... results from the complexity of the ecological interactions involved, from our ignorance of these interactions, and from the considerable problem of manipulating these interactions even if they were satisfactorily understood" (Morgan and Moss, 1981, p. 77). Therefore, Morgan and Moss recommend that in tropical Africa and Southeast Asia, it is necessary and ecologically desirable to develop a tree planting policy involving large plantations, wood lots, windbreaks, and hedgerows; and that this policy should be related to the overall strategy of national development.

The central theme in Morgan and Moss has been reiterated and extended in other studies, for instance, Hall et al. (1982) on biomass energy in developing countries, French (1985) on the economics of biomass energy in developing countries, and Anderson and Fishwick (1984) on woodfuel and deforestation in Africa. French for one argues that, in developing countries, natural forests are a nonrenewable resource, like petroleum. Once these forests are cut down, they are gone forever. While they last, however, they offer a source of "free" energy on which most people will continue to rely. Meanwhile, the low prices of wood from indigenous trees make reforestation extremely difficult, and French bases his observations on his experience in Malawi.
More than French, however, it is Hughes-Cromwick (1985) who employs econometrics and arrives at conclusions which can be tested elsewhere in developing countries. In her study of Nairobi households and their energy use, Hughes-Cromwick examines the determinants of energy demand in the household sector of Nairobi. The author succinctly states the basic hypothesis of the study as follows: "Given a household objective function, relative prices, location of fuel markets, appliance ownership and income determine the quantity and type of fuel consumed in an urban area of a developing country" (Hughes-Cromwick, 1985, p. 267).

Hughes-Cromwick first confirms the assertion that wood is the primary source of energy in developing countries: it accounts for 68% of Kenya's energy utilized. Second, the author finds that variables such as household nominal income, appliance ownership, prices, household size, and geographical distance to fuel markets are major determinants of wood energy demand. Furthermore, Hughes-Cromwick observes that charcoal consumption is negatively related to the charcoal price, and that charcoal is an inferior good; as income rises, less charcoal is demanded.

Clearly, Hughes-Cromwick's findings have significant implications for further research and policy. Kidane (1990) arrives at similar conclusions in his study on demand for energy in rural and urban centers of Ethiopia. Kidane confirms the predominant role of wood energy in developing countries, and also that economic variables such as price and income are important in explaining variations in demand for wood energy. Kidane reiterates the seriousness of the energy crisis in developing
countries. Referring to the specific case of Ethiopia, Kidane (1990, p. 134) states the problem as follows:

The predominant source of energy in rural and urban areas is fuelwood: at the same time the population is 48 million and growing by 2.95% per year. This means that the high demand for fuelwood is depleting the forest resources of the country. This problem has resulted in massive deforestation, soil erosion, desertification, drought and famine.

Ethiopia is a classical example that shows the connection between deforestation, soil erosion, desertification, drought and famine. However, the connection between the demand for woodfuel and deforestation is less understood, it is this which is now the focus of several studies. For instance, Abakah (1990), in his study on wood energy in Ghana, underlines the serious consequences of dependence on wood as a source of energy. According to Abakah, wood is by far the principal source of energy in Ghana, it accounts for about 80% of the total energy consumed in the country. However, Abakah observes that the continued supply and overdependence on woodfuel are a significant factor in accelerated deforestation, soil degradation, and desertification in Ghana.

In his study, Abakah analyzes recent trends in real incomes and the consumption of wood energy in Ghana and concludes that real incomes and the level of inflation influence the demand for wood energy in Ghana. Abakah also observes that the quantity of wood energy consumed is negatively related to income; as income rises, less woodfuel is consumed and therefore woodfuel is an inferior good. Furthermore, the author finds the quantity of wood energy consumed to be positively related to the
level of inflation, as is found to be the case in other developing countries.

In Zambia, the Forest Department of the Ministry of Lands and Natural Resources has, in the past, commissioned various studies to investigate the supply and demand for woodfuel in Zambia. However, it was not until 1985 that a comprehensive project was undertaken on woodfuel supply and demand in Zambia. The project was entitled, "Wood Energy Consumption and Resource Survey," and was undertaken jointly by the United Nations Development Progam (UNDP) and the United Nations Food and Agriculture Organization (FAO), with the cooperation of the Forestry Department of the Ministry of Lands and Natural Resources in Zambia (FAO, 1986a). The project began in March, 1985 and ended in December, 1986. During that time, 896 household interviews were conducted throughout the country.

The UNDP/FAO/Zambia project covered both the rural and urban sectors. In 1988, however, a UNDP/World Bank/Zambia project covered only the urban sector, and was the first detailed study of the urban household energy sector in Zambia (World Bank, 1990). The study was undertaken under the auspices of the UNDP/World Bank, Energy Sector Management Assistance Program (ESMAP) and the cooperating agencies in Zambia were: the Department of Energy of the Ministry of Power, Transport and Communications, the University of Zambia, the Forestry Department, the Central Statistical Office, and the Zambian Electricity Supply Company. In all, the study covered 1,200 households in eight towns.
The studies confirm that wood is the main source of energy in Zambia. Wood energy is used for cooking, heating, and to a limited degree, for lighting. It is also used for fish smoking, tobacco drying, and pottery making.

Firewood is the primary and preferred energy source for rural households while charcoal is more important as a source of income. On the other hand, charcoal is the main woodfuel used by urban households because it is cheaper than petroleum-based fuels, such as gas and kerosene, and because it is easier and cheaper to transport and store than firewood.

However, some critical questions still remain to be answered, among them: does woodfuel present problems which are unique to the Zambian environment? What are the parameters which determine the supply and demand for woodfuel in Zambia? How can Zambia maintain a stable long-run supply of woodfuel?

A number of studies have investigated the production and use of woodfuel in developing countries, but major gaps still exist in our understanding of the role of woodfuel in Zambia. Barnard (1987, p. 349) has stated: "Patterns of woodfuel use vary widely; generalizations based on experience in the hills of Nepal, are of little relevance to the plains of the Punjab or Bangladesh, let alone to the arid zone of sub-Saharan Africa." The purpose of the present study, therefore, is to bridge the information gap on Zambia's principal source of energy.
Statement of the Problem

Studies show that in many developing countries, the rural and urban poor face acute shortages of traditional biomass fuels because of the combined effects of increasing demand and diminishing supplies of traditional fuels. The increase in demand for traditional biomass fuels is considered to be a result of population growth, but it is aggravated by urbanization, which concentrates demand; and by increased oil prices, which makes alternative fuels unaffordable to the rural and urban poor. The decrease in supplies is considered to be a result of deforestation. In turn, deforestation is known to be a result of four principal factors: (1) clearing of land for agriculture, (2) overgrazing by animals, (3) timber removal, and (4) wood energy production.

The purpose of this study is to examine the status of wood as a source of energy in Zambia. On the supply side, Zambia has done well in meeting the demand for timber in the mining industry, but has overlooked the need for woodfuel plantations and agroforestry systems. The mining industry uses timber as pit props and smelting poles. To meet the growing demand for timber, Zambia established large commercial plantations of exotic fast-growing trees, mainly pine and eucalyptus trees. These trees grow faster than indigenous hardwoods and have been able to meet the growing demand for timber, but not the demand for woodfuel (Clarke, 1986).

On the demand side, there is an accelerated demand for charcoal in Zambia as a result of rapid urbanization. Zambia is considered to be the most urbanized country in Africa south of the Sahara. Zambia's rate of
Urbanization is estimated to be 6.7% per annum, much higher than the African average of 5.6% (Republic of Zambia, 1989). Results from the past national censuses in Zambia show that the country's population was 3.5 million in 1963, 4.1 million in 1969, and 5.7 million in 1980. These figures reflect average annual growth rates of 2.6% during 1963-69, and 3.1% during 1969-80. Meanwhile, the urban population grew from 0.7 million or 20.5% of the total population in 1963, to 1.2 million or 29.4% in 1969, to 2.3 million or 39.9% of the total population in 1980. Clearly, there has been a continuous and rapid shift in the spatial distribution of the Zambian population towards the urban areas.

Rapid urbanization has, in turn, accelerated the demand for charcoal. This is because, of the four main sources of energy in Zambia, charcoal is the more attractive source of energy for the urban areas. Electricity and petroleum are relatively expensive and impractical for the shanty towns which surround the cities. Thus, firewood and charcoal are the only alternative fuels. But firewood is heavy and difficult to transport. As a result, firewood is consumed mainly in rural areas, and this leaves charcoal as the preferred fuel in urban areas. In other words, charcoal has certain properties which make it a more attractive source of energy than other sources such as firewood and electricity. Charcoal is relatively light and easy to transport, compared to firewood. Charcoal burns without smoke and provides good consistent heat, unlike firewood. Thus, charcoal provides for domestic use, a fuel which is relatively cheap but high in calorific value and easy to use.
However, charcoal production involves significant environmental costs. This is because charcoal production is in general an inefficient and wasteful process (Clarke, 1986). By definition, charcoal is carbonized wood or other vegetation. A more precise definition is that: "Charcoal is the residue of solid nonagglomerating organic matter, of vegetation or animal origin, that results from carbonization by heat in the absence of air at a temperature of above 300 degrees Celsius" (Emrich, 1985, p. 13). Most charcoal is prepared in traditional earth or pit kilns. The main problem in charcoal production is that during the conversion of wood into charcoal as much as 80% of the heat value of wood is lost to the atmosphere (Clarke, 1986). Besides, in charcoal production, whole live trees are harvested as opposed to the dead branches and twigs which provide much of the rural firewood. Therefore, urban woodfuel is generally more wasteful of wood resources than the rural demand.

The problem of urban woodfuel demand is one that the Government of Zambia itself has come to acknowledge. The government has stated: "woodfuel demand has increased in urban and peri-urban centers while the wood resources have declined. For example, in a place such as Lusaka, the deforestation gradient is 150 km" (Republic of Zambia, 1989, p. 142). As woodlands close to the urban and peri-urban areas are depleted, woodfuel suppliers penetrate farther into the countryside. In the process, the suppliers leave behind bare landscapes; which start the cycle of environmental degradation.

The supply and demand for woodfuel also involves other costs. Scarcity of woodfuel raises the price of woodfuel, and therefore adverse-
ly affects the welfare of the rural and urban poor. In the rural areas, scarcity of woodfuel affects the women and children the most since they are responsible for collecting woodfuel. As woodfuel becomes scarce, preferred tree species are harder to find or become locally extinct, and the women and children need to travel longer distances to reach supplies. Thus, an important part of the real cost of woodfuel is family labor and the opportunity cost of time spent on collecting woodfuel.

The point is that the supply and demand for woodfuel involves significant costs of deforestation, such as loss in soil fertility and breach in the nutrient cycle in deforested areas. On the other hand, afforestation improves the environment. Trees and forests improve the environment in several ways; they use carbon dioxide from the atmosphere and return oxygen to it, they filter air pollution, reduce noise pollution, provide habitat for wildlife, protect watersheds, and prevent soil erosion.

Clearly then, the introduction of energy forestry not only improves the environment, but also has other distinct advantages for Zambia. Energy forestry increases the available wood resources for a diversity of needs. Energy forestry also provides employment in the rural areas. However, the dominant factor is that energy forestry provides a renewable source of energy. Since wood is Zambia's primary source of energy, the introduction of energy forestry can stabilize Zambia's source of energy. A stable long-run supply of energy can, in turn, stabilize the national economy and thereby provide a stimulus for economic development. For these reasons, a study such as the present one is, in essence, a study
about the quality of human life and the quality of the environment.

More specifically, however, this study is designed to test two main hypotheses in the context of Zambia. The hypotheses are:

1. that demand for woodfuel is a function of income, the price of woodfuel, the prices of alternative fuels, inflation, as well as other factors such as investment and the structure of the economy.

2. that large quantities of woodfuel cannot be supplied through natural tree growth and regeneration; therefore it is necessary to implement a program of woodfuel production from tree plantations and agroforestry systems.

This study deals with both the supply and demand for woodfuel in Zambia because the two phenomena complement each other. As the economist Alfred Marshall once observed, supply and demand are like blades of a pair of scissors: they are both required in order for the scissors to cut a piece of paper (Marshall, 1961). Thus, in the present study, the first hypothesis deals with the demand function of wood energy in Zambia. The second hypothesis deals with the supply function of wood energy, in particular, the link between woodfuel cutting and deforestation in Zambia, and therefore complements the first hypothesis.
CHAPTER III. THEORETICAL FRAMEWORK

The Concept of Demand

Demand denotes the quantity of a commodity that a consumer will buy at a given time at different prices (The New Encyclopedia Britannica, 1990; Miller, 1978; Nicholson, 1983). There are two related concepts: a demand function and a demand curve. A demand function is the relationship between the quantity demanded and the determinants of the quantity that the consumer will buy. A demand curve, however, is a special case of a demand function. A demand curve is a graphical representation of the relationship between the quantity of a commodity a consumer will buy and the price of that commodity, other things being held constant. Thus, a demand curve is a special case of a demand function in which interest is focused only on the relationship between a commodity and its price while other factors are held constant.

A contrast is also often made between an ordinary demand function and a compensated demand function (Henderson and Quandt, 1980; Silberberg, 1978). An ordinary demand function is sometimes called a Marshallian demand function, and it gives the quantity of a commodity that a consumer will buy as a function of commodity prices and income, that is:

\[ X^m = X^m(P_1, P_2, \ldots, P_n, M) \]  

(3.1)

where \( X^m \) is the quantity of a commodity that the consumer will buy, \( P_1, P_2, \ldots, P_n \) is a vector of prices, and \( M \) is money income.

Ordinary demand functions can be derived from consumer utility maximization and duality theory (Henderson and Quandt, 1980; Silberberg,
Thus from maximized values of consumer utility,

\[ V(P_1, P_2, \ldots, P_n, m) = U[X(P_1, P_2, \ldots, P_n, m)] \tag{3.2} \]

where \( V \) is an indirect utility function, \( U \) is the direct utility function, and \( X \) is a vector of optimized ordinary demand functions. The indirect utility function depicts the maximized value of the direct utility function subject to the consumer's budget. From duality theory, given an indirect utility function, ordinary demand functions can be obtained by employing Roy's Identity which holds that:

\[ X_i^m(P_1, P_2, \ldots, P_n, m) = \frac{-\partial V / \partial P_i}{\partial V / \partial m} \tag{3.3} \]

where \( X_i^m \) is the quantity of commodity \( i \) that the consumer will purchase, and other terms are as defined before.

On the other hand, a compensated demand function is sometimes called a Hicksian demand function, and it gives the quantity of a commodity that a consumer will buy as a function of commodity prices and a given level of utility, that is:

\[ X^h = X^h(P_1, P_2, \ldots, P_n, U^o) \tag{3.4} \]

where \( X^h \) is the quantity of a commodity that the consumer will buy, \( P_1, P_2, \ldots, P_n \) is a vector of prices, and \( U^o \) is a given level of utility.

Compensated demand functions can be derived from consumer expenditure minimization and also from duality theory (Henderson and Quandt, 1980; Silberberg, 1978). Thus, from minimized values of consumer expenditure,

\[ e(P_1, P_2, \ldots, P_n, U^o) = (P_1, P_2, \ldots, P_n) X(P_1, P_2, \ldots, P_n, U^o) \tag{3.5} \]
where $e$ is the indirect expenditure function and $X$ is a vector of compensated demand functions. The indirect expenditure function depicts the minimized value of the direct level of expenditure subject to a given level of utility. From duality theory, given an indirect expenditure function, compensated demand functions can be obtained by employing Shephard's lemma which holds that:

$$X^h_i(P_1, P_2, \ldots, P_n, U^0) = \frac{\partial e}{\partial P_i}$$

(3.6)

where $X^h_i$ is the quantity of commodity $i$ that the consumer will purchase, and other terms are as defined before.

A concept often employed in energy studies is that of elasticity, and the most frequent elasticity measures estimated are income and price elasticities. Elasticities are often stated in percentage change. Thus, the income elasticity of demand is the change in demand given a one percent change in income. Formally:

$$n_i = \frac{\partial X_i}{\partial m} = \frac{\partial \log X_i}{\partial \log m}$$

(3.7)

where $n_i$ is the income elasticity of demand of commodity $i$, and all the other terms are as defined before. Similarly, the own-price elasticity of demand is the change in demand given a one percent change in the price of that commodity:

$$\varepsilon_{ii} = \frac{\partial X_i}{\partial P_i} = \frac{\partial \log X_i}{\partial \log P_i}$$

(3.8)

where $\varepsilon$ is the own-price elasticity of demand of commodity $i$, and all the other terms are as defined before. Thus, the cross-price elasticity of
demand measures the change in demand given a one percent change in the price of related commodity:

\[
\varepsilon_{ij} = \frac{\delta X_i}{\delta P_j} \frac{P_i}{X_i} = \frac{\delta \log X_i}{\delta \log P_j}
\]  

(3.9)

where \( \varepsilon_{ij} \) is the cross-price elasticity of demand of commodity i, and \( P_j \) is the price of related commodity j.

Clearly then, the concept of elasticity is a measure of responsiveness. As Siddayao (1986, p. 36) has stated: "elasticity is a measure of the responsiveness of a buyer or a supplier to a change in factors that affect quantity demanded or supplied. Elasticity is defined as the ratio of the relative change in a dependent variable to the relative change in an independent variable."

The demand for energy is derived demand in two ways (Siddayao, 1986). First, the demand for energy is derived indirectly from the services such as power and heat. Consumers desire energy services, and energy products are merely the means of obtaining those services. Second, the demand for energy is derived indirectly through the demand for industrial products. Firms demand energy as an input; and this demand is derived from the demand for the firms' output. In general, the derived demand for inputs, including energy, depends on the level of output, the substitution possibilities among inputs, the state of technology, and the relative prices of all inputs.

When the demand for energy is considered on an aggregate or national level, additional determinants of demand include population change and related demographic factors such as the age distribution of the popula-
tion and the distribution of income. For instance, it is often hypothe-
sized that the marginal propensity to consume differs between higher and
lower levels of incomes (Meier, 1984). Therefore, it is frequently
hypothesized that the signs of the partial derivatives of the demand
function for woodfuel are:

\[ X_i = X_i (P_i, P_j, m, \text{and others}) \]  

(3.10)

where \( X_i \) is the quantity of woodfuel demanded, \( P_i \) is the price of
woodfuel, \( P_j \) is the price of alternative fuels, \( m \) is income, and other
things include population. In other words, it is hypothesized that the
quantity of woodfuel demanded rises as the prices of substitute fuels
rise, but falls as the price of woodfuel increased, as the prices of
complementary fuels fall, and as income rises. Thus, it is often
postulated that woodfuel is an inferior good in the sense that the
quantity of woodfuel demanded falls as income rises.

The Concept of Supply

Supply denotes the quantity of a commodity that a producer will sell
at a given time at different prices (The New Encyclopedia Britannica,
1990; Miller, 1978; Nicholson, 1983). There are two related concepts: a
supply function and a supply curve. A supply function is the relation-
ship between the quantity and the determinants of the quantity that a
producer will sell. A supply curve, however, is a special case of a
supply function. A supply curve is a graphic representation of the
relationship between the quantity of a commodity a producer will sell and
the price of that commodity, other things being held constant. Thus, a
supply curve is a special case of a supply function in which interest is focused solely on the relationship between a commodity and its price while other factors are held constant.

A producer's supply function can be derived from profit maximization and duality theory (Henderson and Quandt, 1980; Silberberg, 1978). Profit maximization yields the profit function:

$$\pi = \pi(P, w_1, w_2, \ldots, w_n)$$  \hspace{1cm} (3.11)

where $\pi$ is the profit function, $P$ is output price, $w_1, w_2, \ldots, w_n$ is a vector of input costs. From duality theory, given a profit function, a producer's supply as well as unconditional factor demands can be obtained employing Hotelling's lemma, which holds that:

$$q(P, w_1, w_2, \ldots, w_n) = \frac{\partial \pi}{\partial P}$$

$$X_i(P, w_1, w_2, \ldots, w_n) = \frac{\partial \pi}{\partial w_i}$$  \hspace{1cm} (3.12)

where $q$ is the short- and long-run supply function, $X_i$ is an unconditional demand for the $i$th input.

The objective of a producer is usually considered to be profit maximization, and profit maximization implies cost minimization (Henderson and Quandt, 1980; Silberberg, 1978). However, in place of profit maximization, a producer may only seek to minimize the cost of producing a given level of output. Cost minimization yields the cost function:

$$c = c(q, w_1, w_2, \ldots, w_n)$$  \hspace{1cm} (3.13)

where $c$ is the minimized cost of producing output $q$ for given input prices. From duality theory, given a cost function, a producer's
conditional factor demands can be obtained by employing Shephard's lemma, which holds that:

\[ X_i(q, \omega_1, \omega_2, \ldots, \omega_n) = \frac{\partial c}{\partial \omega_i} \]  \hspace{1cm} (3.14)

where \( X_i \) is the firm's conditional demand for the \( i \)th input, and \( q \) is a given level of output.

As in the case of demand, the concept of elasticity of supply is frequently employed to depict the responsiveness of the quantity supplied to the change in the determinants of supply. Thus, for instance, supply elasticity with respect to change in input cost is:

\[ \epsilon_{ii} = \frac{\partial q_i}{\partial \omega_i} \frac{\omega_i}{q_i} = \frac{\partial \log q_i}{\partial \log \omega_i} \]  \hspace{1cm} (3.15)

where \( \epsilon_{ii} \) is the supply elasticity of commodity \( i \), and all the other terms are as defined before. Similarly, supply elasticity can also be stated in terms of the other determinants of supply.

The supply of energy is determined by the price of energy and input costs of energy production (see equation 3.12). However, there are additional factors which determine the supply of energy, such as weather and technology. Therefore, based on convention and previous research, it is often hypothesized that the signs of the partial derivatives of the supply function of woodfuel are:

\[ q = q(p, \tilde{w}, \text{and others}) \]  \hspace{1cm} (3.16)

where \( q \) is the quantity of woodfuel supplied, \( p \) is the price of woodfuel, \( \tilde{w} \) is a vector of input costs, and the term "others" denotes other determinants of the quantity of woodfuel supplied. In other words, it is
hypothesized that the quantity of woodfuel supplied rises as the price of woodfuel rises and as producers employ improved technology. However, it is expected that the quantity of woodfuel supplied will fall as input costs rise.
CHAPTER IV. MODEL OF WOOD ENERGY DEMAND

Theory of Consumer Demand

Estimation of the parameters of energy demand are often predicated on the assumption of consumer utility maximization. The assumption is that the objective of the consumer is to maximize utility subject to a budget constraint, and utility is defined as the satisfaction the consumer obtains from the commodities he consumes (Henderson and Quandt, 1980; Silberberg, 1978). That is:

\[ u = u(X_1, X_2, \ldots, X_n; \text{other things}) \]  \hspace{1cm} (4.1)

where \( u \) represents the satisfaction or utility the consumer derives from the commodities he consumes; \( (X_1, X_2, \ldots, X_n) \) represents a vector of commodities; and other things represent other factors from which the consumer also obtains satisfaction. These other factors include love, religion, aesthetics, and so on. However, for simplicity, these other factors are assumed to be held constant and, therefore, utility is conceptualized only in terms of the consumption of commodities. In addition, it is assumed that the utility function is increasing, strictly quasi-concave, continuous, and twice differentiable; that is, the function is well-behaved.

The objective of the consumer is to maximize the utility function subject to a budget constraint. In other words, the consumer has a budget constraint, which is the amount of income available to allocate to the purchase of commodities. The income is limited and, therefore, it is a constraint to the consumer. That is:
where \( P_i \) represents the price of commodity \( x_i \), \( P_i X_i \) is the expenditure on commodity \( X_i \), and \( m \) is the total budget of the consumer. The budget constraint says that total expenditure cannot exceed income. Thus, the objective of the consumer is to:

\[
\text{maximize } u = u(X_1, X_2, \ldots, X_n)
\]

subject to \( \sum_{i=1}^{n} P_i X_i \leq m \)

and \( X_1, X_2, \ldots, X_n \geq 0 \) \hspace{1cm} (4.3)

The objective function requires that the budget constraint is an inequality, that is, \( \sum_{i=1}^{n} P_i X_i \leq m \), and also requires the variables to be non-negative, that is, \( X_1, X_2, \ldots, X_n \geq 0 \). This is a nonlinear programming problem (Chaign, 1974; Pfaffenberger and Walker, 1976).

The conditions that characterize an optimal solution to a nonlinear programming problem are called the Kuhn-Tucker conditions, named after the authors, H. W. Kuhn and A. W. Tucker, and are considered to be "...the single most important analytical result in nonlinear programming" (Chiang, 1974). The Kuhn-Tucker conditions are often stated in terms of necessary and sufficient conditions for a maximum. For example, given the nonlinear program:

\[
\text{maximize } Z = F(X_1, X_2, \ldots, X_n)
\]

subject to \( g^1(X_1, X_2, \ldots, X_n) \leq r_1 \)
\[ g^2(x_1, x_2, \ldots, x_n) \leq r_2 \]
\[ \ldots \ldots \ldots \ldots \ldots \]
\[ g^m(x_1, x_2, \ldots, x_n) \leq r_m \]
and \[ x_1, x_2, \ldots, x_n \geq 0 \]  \hspace{1cm} (4.4)

Then we define the Lagrangean Function as:
\[ L = F(x_1, x_2, \ldots, x_n) + \sum_{i=1}^{n} \lambda_i [x_i - g^i(x_1, x_2, \ldots, x_n)] \]  \hspace{1cm} (4.5)

The Kuhn-Tucker conditions for (4.5) are:
\[ \frac{\partial L}{\partial x_j} = \frac{\partial F}{\partial x_j} + \sum_{i=1}^{m} \lambda_i g^i \leq 0, \quad x_j \geq 0, \quad x_j \frac{\partial L}{\partial x_j} = 0 \]
\[ \frac{\partial L}{\partial \lambda_i} = g^i \geq 0, \quad \lambda_i \geq 0, \quad \lambda_i \frac{\partial L}{\partial \lambda_i} = 0 \]  \hspace{1cm} (4.6)

where, \( i = 1, 2, \ldots, m \) and \( j = 1, 2, \ldots, n \). These Kuhn-Tucker conditions are necessary conditions for a maximum if the "constraint qualification" condition is met (Chaign, 1974). The constraint qualification condition basically ensures that the region of points in the X-space not ruled out by the constraints, called the feasible region, has a shape that is well-behaved. Feasible regions are not well-behaved if the constraints become tangent to one another. Such regions are not often encountered in economics, and this is considered to be the case in the present study.

In addition, the Kuhn-Tucker are sufficient conditions for a maximum if two conditions are satisfied (Chaign, 1974). First, the objective function, \( F(x_1, x_2, \ldots, x_n) \) must be concave. Second, each constraint, \( g^i(x_1, x_2, \ldots, x_n) \) must be convex. Therefore, the Kuhn-Tucker
conditions are necessary and sufficient if the constraint qualification is satisfied and if the objective function is concave, and if each constraint is convex.

Now, returning to the special case of consumer utility maximization, the problem of the consumer is to:

\[
\text{maximize } U = U(X_1, X_2, \ldots, X_n)
\]

subject to \[\sum_{i=1}^{n} P_i X_i \leq m\]

and \[X_1, X_2, \ldots, X_n \geq 0\] \hspace{1cm} (4.7)

where all the terms are as defined before. The Lagrangean Function for this problem is:

\[
L = U(X_1, X_2, \ldots, X_n) + \lambda(m - \sum_{i=1}^{n} P_i X_i)
\]

where \(\lambda\) is defined as the marginal utility of income. The Kuhn-Tucker conditions are:

\[
\frac{\partial L}{\partial X_1} = \frac{\partial U}{\partial X_1} - \lambda P_i \leq 0, X_1 \geq 0, X_1 \frac{\partial L}{\partial X_1} = 0
\]

\[
\frac{\partial L}{\partial \lambda} = (m - \sum_{i=1}^{n} P_i X_i) \geq 0, \lambda \geq 0, \lambda \frac{\partial L}{\partial \lambda} = 0
\] \hspace{1cm} (4.9)

These Kuhn-Tucker conditions are necessary and sufficient conditions for a maximum if the constraint qualification is satisfied and if the objective function \(U(X_1, X_2, \ldots, X_n)\) is concave, and if the constraint \[\sum_{i=1}^{n} P_i X_i \leq m\] is convex.
However, it should be noted that consumer utility maximization is usually stated in terms of classical first-order conditions for a maximum, rather than the Kuhn-Tucker conditions. Yet, the two sets of conditions are related. Just as the consumer utility maximization problem is a special case of the nonlinear programming problem, the classical first-order conditions are a special case of the Kuhn-Tucker conditions under certain circumstances (Chaign, 1974; Intriligator, 1971). These circumstances are that: (1) boundary solutions are ruled out, characterized as \( \frac{\partial L}{\partial x_i} = 0 \) and \( x_i = 0 \); (2) local maxima are ruled out, characterized as \( \frac{\partial L}{\partial x_i} < 0 \) and \( x_i = 0 \); (3) consideration is made only of interior solutions, characterized as \( \frac{\partial L}{\partial x_i} = 0 \) and \( x_i > 0 \).

Thus, under such circumstances, the first-order conditions of the consumer maximization problem (4.7) are:

\[
\frac{\partial L}{\partial x_i} - \lambda p_i = 0 \quad \sum_{i=1}^{n} \frac{\partial L}{\partial \lambda} - m \quad \sum_{i=1}^{n} P_i x_i = 0
\]  

(4.10)

Then, the second-order conditions for a maximum are those on the bordered Hessian matrix:

\[
H = \begin{bmatrix}
L_{11} & L_{12} & \cdots & L_{1n} & L_{1\lambda} \\
L_{21} & L_{22} & \cdots & L_{2n} & L_{2\lambda} \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
L_{n1} & L_{n2} & \cdots & L_{nn} & L_{n\lambda} \\
L_{\lambda 1} & L_{\lambda 2} & \cdots & L_{\lambda n} & L_{\lambda \lambda}
\end{bmatrix}
\]
where $L_{11} = \frac{\partial^2 L}{\partial x_1^2}$; $L_{12} = \frac{\partial^2 L}{\partial x_1 \partial x_2}$; $L_{1n} = \frac{\partial^2 L}{\partial x_1 \partial x_n}$; $L_{1\lambda} = \frac{\partial^2 L}{\partial x_1 \partial \lambda}$, and so on. The second-order conditions for a maximum require that the principal minor of $H$ alternate in sign, with the first minor being positive. These conditions are met by assuming that the Hessian matrix $H$ is negative definite; that is, the utility function is strictly quasi-concave (Silberberg, 1974). Thus, in this case, the first-order conditions are necessary and sufficient conditions for a maximum.

When first-order and second-order conditions are satisfied, we solve the system of the unknown of the first-order conditions for $X_1^*, X_2^*, \ldots, X_n^*$ and $\lambda$ in terms of prices and incomes. The resulting solutions are:

$$X_i^* = X_i^*(P_1, P_2, \ldots, P_n, m)$$

where the $X_i^*(P_1, P_2, \ldots, P_n, m)$ are known as ordinary demand functions. Demand functions also have the important property that:

$$X_i^*(\alpha P_1, \alpha P_2, \ldots, \alpha P_n, \alpha m) = \alpha X_i^*(P_1, P_2, \ldots, P_n, m)$$
where $\alpha$ is a constant. This equation says that if we multiply $P_1$, $P_2$, ..., $P_n$ and $m$ by a constant, $\alpha$, the optimal quantities consumed will remain unchanged. In other words, consumer demand functions are homogenous of degree zero in prices and income. This property is important because it says that the consumption decision is made in response to relative price and income levels. To state this in another way: the demand for goods depends on price ratios, called relative prices, and the ratio of money to a given price, called real income. Therefore, if all prices and income change in the same proportion, the quantities demanded remain unchanged.

Another important property of the demand functions in equation (4.12) is that when they are substituted into the utility function (4.1), they yield an indirect utility function:

$$V(P_1, P_2, \ldots, m) = U[X^*_i(P_1, P_2, \ldots, m)] \quad (4.14)$$

where $V$ is an indirect utility function depicting the optimal level of utility a consumer can achieve as a function of the price of goods and income. Thus, given the indirect utility function and employing Roy's Identity:

$$X^*_i(P_1, P_2, \ldots, P_m, m) = \frac{-\partial V/\partial P_i}{\partial V/\partial M} \quad (4.15)$$

where $X^*_i$ is an ordinary demand function (see Chapter III).

This, then, is a brief review of demand theory on which the estimation of energy demand is often based. The point of the brief review presented here is this, that if the objective function of the consumer is to maximize utility subject to a budget constraint, then certain charac-
teristics of consumption behavior are implied that can be substantiated or refuted by empirical observation.

Assumptions of Wood Energy Demand Model

The basic assumption of the wood energy demand model of the present study is that of separability. The concept of separability is considered to be the result of the work of Leontif (1947) and Sono (1960), and it is one of the basic assumptions often made in demand analysis (Johnson et al., 1984).

Separability is essentially the idea that commodities within each subset possess some common characteristics (Johnson et al., 1984; Henderson and Quandt, 1980). Therefore, choices by the consumer about how to allocate expenditure can be made independently among groups. For instance, commodities may naturally be grouped into food, shelter, clothing, and energy. According to the concept of separability, choosing how to allocate a given food expenditure between beef and fish can be made independently of decisions about how to allocate a given energy expenditure between charcoal and firewood. In other words, according to the concept of separability, the consumer makes consumption decisions in two stages. First, the consumer allocates expenditures between groups or subsets of commodities. Second, the consumer allocates expenditure within each group or subset. This, then, is the essence of separability: that the consumer allocates expenditures independently between groups of commodities.
The extreme form of separability is that of additivity. Additive functions are a special case of separable functions in which the marginal utility of every good is independent of the quantity consumed of all other goods. Thus, additive functions may be considered as one good in each group.

In consumer theory, there are several types of separability and additivity which have been advanced, but the main ones are strong and weak separability and additivity (Johnson et al., 1984; Henderson and Quandt, 1980). A utility function is strongly separable if it can be written as:

$$U = F[U_1(X_1) + U_2(X_2) + \ldots + U_n(X_n)] = F[\Sigma U_i(X_i)]$$  \hspace{1cm} (4.16)

where $X_1, X_2, \ldots, X_n$ are groups of commodities. When a utility function $F[\Sigma U_i(X_i)]$ is strongly separable, the marginal rate of substitution between two commodities belonging to two different groups is zero.

A utility function is strongly additive if it can be written as:

$$U = U_1(X_1) + U_2(X_2) + \ldots + U_n(X_n) = \Sigma U_i(X_i)$$  \hspace{1cm} (4.17)

where $X_1, X_2, \ldots, X_n$ are commodities. A strongly additive function has the property that all cross partials for any pair of commodities are equal to zero, that is:

$$\frac{\partial^2 U}{\partial X_i \partial X_j} = 0 \text{ for all } i \neq j$$  \hspace{1cm} (4.18)

A utility function is weakly separable if it can be written as:
\[ U = F[U_1(X_1), U_2(X_2), \ldots, U_n(X_n)] = F[U_1(X_1)] \] (4.19)

where \( X_1, X_2, \ldots, X_n \) are groups of commodities. When a utility function \( F[U_1(X_1)] \) is weakly separable, the marginal rate of substitution between commodities belonging to different groups is zero.

A utility function is weakly additive if it can be written as:

\[ U = U_1(X_1) + U_2(X_2) + \ldots + U_n(X_n) = \sum_{i=1}^{n} U_i(X_i) \] (4.20)

where \( X_1, X_2, \ldots, X_n \) are groups of commodities. A weakly additive function has the property that all cross partials for pairs of commodities in different groups are equal to zero, that is:

\[ \frac{\partial^2 U}{\partial x_i \partial x_j} = 0 \text{ for all } i \neq j \] (4.21)

The point then is that separability depicts that there is a two-stage process whereby some decisions are made independently of other decisions. Thus, by assuming separability, some decisions can be analyzed independently of other decisions, and therefore many problems become tractable. This is why the assumption of separability is often made in economic analysis. From an empirical standpoint, separability makes it possible to reduce the number of parameter estimates. Since commodities belong to different groups of the utility function, substitution between the commodities is limited, and therefore separability reduces the parameters estimates. Since commodities belong to different groups of the utility function, substitution between the commodities is limited, and therefore separability reduces the parameter estimates associated with a demand system. Furthermore, with fewer parameters to
be estimated the empirical estimation can proceed with less information. It is for these reasons that separability is the basic assumption of the model of the present study. However, the usual assumptions that are made about consumer behavior are retained (that is, the utility function of the consumer is increasing, strictly quasi-concave, continuous, and twice differentiable). Based on these assumptions, here then is the structure of the model of wood energy demand.

The Structure of the Model

The model of the present study is adopted from the study by Dias-Bandaranaike and Munasinghe (1983), and this has been reviewed by Plourde and Ryan (1985). The model assumes the consumer has the utility function:

\[ U = U(B, N) \]  \hspace{1cm} (4.22)

where \( U(B, N) \) is the utility function, \( B \) is the quantity of all goods and services consumed except energy, and \( N \) is the total quantity of energy services consumed. In turn, the quantity of energy services consumed consists of wood energy services (\( W \)), and substitute energy services (\( S \)). Thus, we have:

\[ N = N(W, S) \]  \hspace{1cm} (4.23)

where \( N(W, S) \) is the energy function, \( W \) and \( S \) are as defined before. Substituting (4.23) into (4.22) we obtain:

\[ U = U[B, N(W, S)] \]  \hspace{1cm} (4.24)

where all the variables are defined as before.
Clearly then, the utility function (4.24) is by assumption weakly separable; but this is not something which is explicitly stated by Dias-Bandaranaike and Munasinghe (1983). In the present study, however, it is explicitly assumed that the utility function is weakly separable: \( U[B, N(W, S)] \), where \( B \) is a group of all goods and services except energy, and \( N(W, S) \) is a group of energy goods.

In addition, it is assumed that the consumer has the budget constraint:

\[
P_bB + P_wW + P_sS = M \tag{4.25}
\]

where \( M \) is income; \( P_b, P_w \) and \( P_s \) are the prices of non-energy goods, wood energy services, and wood energy substitutes, respectively. The objective function of the consumer is to maximize utility subject to the budget constraint. That is:

\[
\begin{align*}
\text{maximize} & \quad U = U[B, N(W, S)] \\
\text{subject to} & \quad P_bB + P_wW + P_sS = M 
\end{align*} \tag{4.26}
\]

The Lagrangean Function for this problem is:

\[
L = U[B, N(W, S)] + \lambda(M - P_bB - P_wW - P_sS) \tag{4.27}
\]

where \( \lambda \) is a Lagrange multiplier or the marginal utility of income. The first-order conditions for this problem are:

\[
\begin{align*}
\frac{\partial L}{\partial B} &= \frac{\partial U}{\partial B} - P_b = 0 \\
\frac{\partial L}{\partial W} &= \frac{\partial U}{\partial W} - P_w = 0 \\
\frac{\partial L}{\partial S} &= \frac{\partial U}{\partial S} - P_s = 0 \\
\frac{\partial L}{\partial \lambda} &= M - P_bB - P_wW - P_sS = 0 \tag{4.28}
\end{align*}
\]
where all the variables are defined as before. Assuming the second-order conditions are satisfied, the first-order conditions are solved for the unknowns to obtain:

\[ X_i^* = X_i^*(P_b', P_w', P_s', M) \]

\[ \lambda^* = \lambda^*(P_b', P_w', P_s', M) \]  

(4.29)

where i = B, W, S, and are ordinary demand functions for non-energy goods and services, wood energy services, and substitute energy services, respectively.

However, because of the assumption of separability, attention is, in this case, focused on the energy subgroup N, that is, on the determinants of wood energy without the price vector \( P_b \) in equation (4.30). In other words, because of separability, the demand for wood energy can be expressed as a function of expenditure on the energy subgroup and the price vector of the goods in the energy subgroup only. From the budget constraint, equation (2.25), the expenditure on the energy subgroup is:

\[ P_w + P_s S = M_N \]  

(4.30)

where \( M_N = Y - P_b \) is total expenditure on the energy subgroup. Then equation (4.23) is maximized subject to (4.30), that is:

\[
\text{maximize } N = N(W, S) \\
\text{subject to } P_w + P_s S = M_N
\]  

(4.31)

The Lagrangean Function for this problem is:

\[ L = N(W, S) + \lambda(M_N - P_w - P_s S) \]  

(4.32)

where all the variables are defined as before. The first-order conditions for this problem are:
where all the variables are defined as before. Assuming the second-order conditions are satisfied, the first-order conditions are solved for the unknowns to obtain:

\[
\frac{\partial L}{\partial w} = \frac{\partial N}{\partial w} - P_w = 0 \\
\frac{\partial L}{\partial s} = \frac{\partial N}{\partial s} - P_s = 0 \\
\frac{\partial L}{\partial \lambda} = M_n - P_w - P_s = 0
\] (4.33)

It may be noted that this model may be extended to deal with industrial demand for wood energy (Dias-Banderanaike and Monasighe, 1983). The basic assumption in this case is that of a weakly separable production function:

\[
Q = F(J, N)
\] (4.35)

where \(Q\) is output, \(F(J, N)\) is the production function, \(N\) is the quantity of energy services employed, and \(J\) is the quantity employed of all other inputs such as land, labor and capital. In turn, the quantity of energy services employed consists of wood energy services \((W)\) and substitute energy services \((S)\). Thus, we have:

\[
N = N(W, S)
\] (4.36)
where \( N(W, S) \) is the energy function. Substituting (4.36) into (4.35) we obtain:

\[
Q = F[J, N(W, S)]
\]  

(4.37)

where all the variables are defined as before. It is assumed that this function is well-behaved (i.e., the function is increasing, twice-differentiable, strictly quasi-concave function when output is maximized or cost is minimized and a strictly concave function when profit is maximized). The model also assumes the firm has the total cost function:

\[
C = P_J J + P_W W + P_S S
\]  

(4.38)

where \( C \) is total cost, \( P_J, P_W, \) and \( P_S \) are the input prices of non-energy factors of production, wood energy services, and wood energy substitutes, respectively.

The objective of the firm is usually considered to be profit maximization, and profit maximization implies cost minimization (Henderson and Quandt, 1980; Silberberg, 1978). However, under the rubric of industrial wood energy demand, there are certain institutions such as schools and other government institutions whose objective is net profit maximization. Therefore, it is assumed that the optimization problem of the firm is cost minimization; that is, to choose its input combination of \( J, W, \) and \( S \) so as to minimize total production costs subject to the technological constraint that output is feasible. The objective of the firm is:

\[
\text{minimize} \quad C = P_J J + P_W W + P_S S
\]

subject to \( Q = F[J, N(W, S)] \)  

(4.39)
The Lagrangean Function for this problem is:

\[ L = P_j J + P_w W + P_s S + \lambda Q - F(J, N(W, S)) \]  \hspace{1cm} (4.40)

where \( \lambda \) is a Lagrangean multiplier. The first-order conditions for a minimum are:

\[
\frac{\partial L}{\partial J} = P_j - \lambda \frac{\partial F}{\partial J} = 0
\]

\[
\frac{\partial L}{\partial W} = P_w - \lambda \frac{\partial F}{\partial W} = 0
\]

\[
\frac{\partial L}{\partial S} = P_s - \lambda \frac{\partial F}{\partial S} = 0
\]

\[
\frac{\partial L}{\partial \lambda} = Q - F(J, N(W, S)) = 0
\]  \hspace{1cm} (4.44)

where all the variables are as defined before. When second-order conditions for a minimum hold, the first-order conditions are solved to obtain:

\[
X_i^c = X_i^c(P_j, P_w, P_s, Q)
\]

\[
\lambda^c = \lambda^c(P_j, P_w, P_s, Q)
\]  \hspace{1cm} (4.42)

where \( i = J, W, S \), and are the compensated or Hicksian factor demand functions for non-energy inputs, wood energy, and substitute energy services, respectively. However, because of the assumption of separability, the demand for wood energy can be expressed as a function of energy prices and the quantity of energy services employed. From the total cost function (4.38), the cost of the energy subgroup is:

\[
C_E = P_w W + P_s S
\]  \hspace{1cm} (4.43)

where \( C_E = C - P_j J \) is the cost of energy inputs. Then equation (4.36) is minimized subject to (4.43), that is:
minimize \( C_E = P_w W + P_s S \)
subject to \( N = N(W, S) \)  \( (4.44) \)

The Lagrangean function for this problem is:
\[ L = P_w W + P_s S + \lambda [N - N(W, S)] \]  \( (4.45) \)

The first-order conditions for the problem are:
\[ \frac{\partial L}{\partial w} = P_w - \lambda \frac{\partial N}{\partial w} = 0 \]
\[ \frac{\partial L}{\partial s} = P_s - \lambda \frac{\partial N}{\partial s} = 0 \]
\[ \frac{\partial L}{\partial \lambda} = N - N(W, S) = 0 \]  \( (4.46) \)

where all the variables are defined as before. When second-order conditions for a minimum hold, the first-order conditions are solved to obtain:
\[ x_i^c = x_i^c(P_w, P_s, N) \]
\[ \lambda^c = \lambda^c(P_w, P_s, N) \]  \( (4.47) \)

where \( i = W, S \), and they are compensated factor demand functions for wood energy and substitute energy services. Thus, industrial wood energy demand is, in this case, a function of the energy price vector and the quantity of energy employed.

In the present study, however, the parameters of industrial wood energy demands are not estimated because industrial wood energy demand is only a small component of total energy demand and because of the unavailability of industrial wood energy consumption data. Rather, the estimation is restricted to consumer wood energy demand which accounts for 85% of total wood energy demand in Zambia.
Model Estimation

In estimating demand, a choice has to be made about the form of the demand function. The most frequent choices made are the linear and the log-linear (the double-log) demand functions (Yoshihara, 1969; Parks, 1969; Klevmarken, 1979). The linear and log-linear forms are restrictive in their assumptions about the underlying utility functions of households and production functions of the firms. In particular, the underlying functions must be linear, implying that elasticities of substitution in consumption and production are constant. In other words, a common assumption in empirical research is that of constant elasticity of demand; and this may be stated as:

\[ Y_i = A_i M^{\beta_{i0}} \prod_{j=1}^{n} P_j^{\beta_{ij}} \epsilon_i \]  

(4.48)

where \( Y_i \) is a demand function such as \( B^*, W^*, \) and \( S^* \) in (4.31); \( A_i, \beta_{i0}, \) and \( \beta_{ij} \) are constants; and \( \epsilon_i \) is an error term (Yoshihara, 1969). The linear form of this equation, (4.48), is:

\[ Y_i = \beta_i + \beta_{i0} M + \sum_{j=1}^{n} \beta_{ij} P_j + E_i \]  

(4.49)

where \( \beta_i, \beta_{i0}, \beta_{ii}, \) and \( \beta_{ij} \) are the parameters of the equation and \( E_i \) is an error term. The parameters measure the change in \( Y_i \) due to the change in income, \( M; \) the change in own-price, \( P_i; \) and the change in prices of related goods and services, \( P_j. \) The log-linear form of equation (4.48) is:
\[
\log Y_i = \beta_i + \beta_{io} \log M + \sum_{j=1}^{n} \beta_{ij} \log P_j + E_i
\]

\[
= \beta_i + \beta_{io} \log M + \beta_{ii} \log P_i + \sum_{j \neq i} \beta_{ij} \log P_j + E_i \quad (4.50)
\]

where all the terms are defined as before. A choice then has to be made between equations (4.41) and (4.42) because the two equations are not the same. As Maddala (1988, p. 177) has stated: "When comparing the linear with the log-linear forms, we cannot compare the \( R^2 \)'s because \( R^2 \) is the ratio of explained variance to the total variance and the variances of \( Y \) and \( \log Y \) are different. Comparing \( R^2 \)'s in this case is like comparing two individuals A and B, where A eats 65% of a carrot cake and B eats 70% of a strawberry cake. The comparison does not make sense because there are two different cakes." Therefore, we choose one of them.

For the estimation of demand functions, the log form is often preferred for two main reasons. First, it is the case that the problem of heteroskedasticity is sometimes solved by estimating the regression in log-linear form (Maddala, 1988). Second, it is easy to interpret the parameters or coefficients of the regression. They are elasticities. Thus, for instance, in equation (4.50):

\[
\frac{\partial \log Y_i}{\partial \log M} = \beta_{io} \quad (4.51)
\]

is the income elasticity of demand: it measures the percentage change in \( Y_i \) given a 1% change in income. Then, the parameters \( \beta_{ii} \) and \( \beta_{ij} \) are respectively, the own-price and the cross-price elasticities of demand.
It is for these reasons that the log form is employed in the present study.

The models suggested by equations (4.49) and (4.50) are static models which explain energy demand as a function of income, of the energy price and of the prices of related energy sources. However, these simple static models have one basic deficiency, they do not allow for long-term changes in energy demand (Kouris, 1981). Over time, energy demand changes, mainly because the economy in general and the structure of the energy market, in particular, change. This implies that elasticities change over time.

Over time, trends in elasticity values derive from corresponding trends in the economy, and other models are often employed to account for the long-run adjustment of energy demand. One such model is to state energy demand as a function of geometric lag distribution of income and prices (Kouris, 1981). This is done equivalently by introducing lags or autoregression on energy demand. The general form of the autoregressive process is:

\[
Y_t = C + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots + \phi_p Y_{t-p} + a_t
\]  

(4.52)

where \( P \) is the order of autoregression, AR(\( P \)); \( c, \phi_1, \ldots, \phi_p \) are constants; and \( a_t \) is an error term. For a one-period lag, there is a first-order autoregressive model, AR(1); for a two-period lag, there is a second-order autoregressive model, AR(2); and so on. Empirical estimates of energy demand usually employ AR(1) and AR(2) models. The present study employs an AR(1) model, and this modifies equation (4.50) as follows:
\[ \log Y_i = \beta_1 + \beta_{10} \log M + \beta_{1i} \log P_i + \sum_{j \neq 1} \beta_{1j} \log P_j + \beta_{1k} \log Y_{i-1} + E_i \]  

(4.53)

where \( \beta_{10} \), \( \beta_{1i} \), and \( \beta_{1j} \) are the short-run income, own-price and cross-price elasticities, respectively; and \( \beta_{1i} / 1 - \beta_{1k} \), \( \beta_{1i} / 1 - \beta_{1k} \), and \( \beta_{1j} / 1 - \beta_{1k} \) are the long-run income, own-price and cross-price elasticities, respectively.

Equation (4.53) is the standard demand equation; and additional determinants of demand are often added to the standard equation. In the present study, the standard variable added to equation (4.53) is inflation (\( P \)). In other words, the energy demand equation (4.53) is designed to estimate the effects of standard determinants of energy demand, and these are income, price, and inflation. The major exception not added to the set of the regressors is population, \( N \). The variable population is omitted as a regressor because the data on firewood and charcoal consumption in the rural and urban areas are calculated on the basis of the population in these sectors. This is the existing practice of calculating woodfuel consumption data, and it is employed because woodfuel consumption and supply data do not often enter national accounts statistics. Total consumption of firewood and charcoal are often calculated on the basis of population and the per capita consumption of firewood and charcoal obtained from household surveys.

In Zambia, the best available data on per capita consumption of firewood and charcoal are those of the FAO/Forestry Department Wood Energy Consumption and Resource Survey of 1985 (FAO, 1986a). According
to this survey and the estimates adopted by the Department of Energy in Zambia, rural household consumption of firewood is 1,241 kg/capita/year, and of charcoal is 22 kg/capita/year; while urban household consumption of firewood is 94 kg/capita/year, and of charcoal is 190 kg/capita/year. It is on the basis of these figures, together with sectoral population figures, that consumption of firewood and charcoal are in the present study calculated by sector in metric tonnes/year. Therefore, on a priori grounds, population is omitted as a regressor in this study. In addition, government subsidies on energy consumption in Zambia are omitted as regressors because these data are not readily available.

Clearly, problems of data restrict the number of variables to be included as regressors. This is expected when modeling a developing country like Zambia. As Obidegwu and Nziramasanga (1981, p. 36) have observed:

Data can impose severe limitations in building an econometric model. In the case of Zambia, there are problems concerning both quality and quantity of data. Zambia has existed as a separate economic entity only since 1964, so the length of time-series data is limited. . . . In addition, there are several interesting variables for which no data are available or for which the data available are not of sufficient length to be used in estimation.

Besides, it has been recognized that the standard determinants of demand such as income, price, population and inflation do not adequately measure the effects on energy demand of the structural transformation of the economy. It has been argued, "the demand for energy is highly influenced by the changing pattern of production land- and labor-inten-
sive goods to capital- and energy-intensive commodities. Consequently, standard determinants of the demand cannot fully explain the consumer behavior" (Pourgerani and von Hirschhausen, 1991, p. 239). For this reason, additional variables are added to the standard determinants in order to capture the effects of structural transformation on energy demand. These variables are sometimes referred to as structural variables.

There are two structural variables which are sometimes added to the standard energy demand equation. These are: (1) the growth rate of gross capital formation, and (2) the growth rate of agricultural output. It is hypothesized that capital accumulation in the modern, urban industrial sector increases dependence on capital-intensive and energy-intensive technologies and, therefore, increases the demand for energy. It is also hypothesized that energy consumption increases with increased agricultural mechanization and the increased application of chemical fertilizer. Clearly, the agricultural output variable refers to the use of fossil-fuel energy, especially oil-based products. Therefore, in the present study, only one structural variable is considered: the growth rate of gross capital formation. And instead of the growth rate of capital formation, the structural variable employed here is the growth rate of investment (I), because investment is by definition gross fixed capital formation minus changes in stocks (see Table 4.1). Thus, by the standard demand variables and inflation (P), and the structural variable growth in investment (I), equation (4.45) becomes:
Table 4.1. GDP and investment in Zambia: 1966-1987 (millions of Kwacha)

<table>
<thead>
<tr>
<th>Year</th>
<th>Real GDP</th>
<th>GFCF</th>
<th>Changes in Stocks</th>
<th>Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>5,358</td>
<td>176</td>
<td>50</td>
<td>226</td>
</tr>
<tr>
<td>1967</td>
<td>5,628</td>
<td>225</td>
<td>49</td>
<td>274</td>
</tr>
<tr>
<td>1968</td>
<td>5,773</td>
<td>265</td>
<td>56</td>
<td>321</td>
</tr>
<tr>
<td>1969</td>
<td>5,956</td>
<td>277</td>
<td>-39</td>
<td>238</td>
</tr>
<tr>
<td>1970</td>
<td>6,149</td>
<td>350</td>
<td>-12</td>
<td>338</td>
</tr>
<tr>
<td>1971</td>
<td>6,145</td>
<td>369</td>
<td>47</td>
<td>416</td>
</tr>
<tr>
<td>1972</td>
<td>6,707</td>
<td>409</td>
<td>12</td>
<td>421</td>
</tr>
<tr>
<td>1973</td>
<td>6,645</td>
<td>413</td>
<td>46</td>
<td>459</td>
</tr>
<tr>
<td>1974</td>
<td>7,092</td>
<td>502</td>
<td>190</td>
<td>692</td>
</tr>
<tr>
<td>1975</td>
<td>6,919</td>
<td>602</td>
<td>40</td>
<td>642</td>
</tr>
<tr>
<td>1976</td>
<td>7,218</td>
<td>445</td>
<td>7</td>
<td>452</td>
</tr>
<tr>
<td>1977</td>
<td>6,871</td>
<td>483</td>
<td>7</td>
<td>490</td>
</tr>
<tr>
<td>1978</td>
<td>6,910</td>
<td>437</td>
<td>100</td>
<td>537</td>
</tr>
<tr>
<td>1979</td>
<td>6,700</td>
<td>450</td>
<td>-74</td>
<td>376</td>
</tr>
<tr>
<td>1980</td>
<td>6,903</td>
<td>646</td>
<td>55</td>
<td>701</td>
</tr>
<tr>
<td>1981</td>
<td>7,329</td>
<td>610</td>
<td>63</td>
<td>673</td>
</tr>
<tr>
<td>1982</td>
<td>7,123</td>
<td>618</td>
<td>-15</td>
<td>603</td>
</tr>
<tr>
<td>1983</td>
<td>6,983</td>
<td>615</td>
<td>-40</td>
<td>575</td>
</tr>
<tr>
<td>1984</td>
<td>6,958</td>
<td>623</td>
<td>101</td>
<td>724</td>
</tr>
<tr>
<td>1985</td>
<td>7,072</td>
<td>725</td>
<td>329</td>
<td>1,054</td>
</tr>
<tr>
<td>1986</td>
<td>7,113</td>
<td>1,385</td>
<td>1,701</td>
<td>3,086</td>
</tr>
<tr>
<td>1987</td>
<td>7,097</td>
<td>1,929</td>
<td>579</td>
<td>2,508</td>
</tr>
</tbody>
</table>

Table 4.2. Select indices and exchange rate of Zambian Kwacha: 1966-1987 (exchange rate is value of 1 Kwacha in U.S. dollars)

<table>
<thead>
<tr>
<th>Year</th>
<th>Exchange Rate</th>
<th>CPI</th>
<th>EPI</th>
<th>WPI</th>
<th>OVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>1.40</td>
<td>11.3</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1967</td>
<td>1.40</td>
<td>11.9</td>
<td>107.3</td>
<td>100</td>
<td>112.0</td>
</tr>
<tr>
<td>1968</td>
<td>1.40</td>
<td>13.1</td>
<td>115.8</td>
<td>102</td>
<td>94</td>
</tr>
<tr>
<td>1969</td>
<td>1.40</td>
<td>13.5</td>
<td>102.2</td>
<td>120.8</td>
<td>92.4</td>
</tr>
<tr>
<td>1970</td>
<td>1.40</td>
<td>13.8</td>
<td>95.7</td>
<td>128.9</td>
<td>121.8</td>
</tr>
<tr>
<td>1971</td>
<td>1.40</td>
<td>14.7</td>
<td>91.4</td>
<td>131.0</td>
<td>137.9</td>
</tr>
<tr>
<td>1972</td>
<td>1.40</td>
<td>15.4</td>
<td>93.6</td>
<td>131.3</td>
<td>128.9</td>
</tr>
<tr>
<td>1973</td>
<td>1.40</td>
<td>16.4</td>
<td>88.9</td>
<td>133.5</td>
<td>135.8</td>
</tr>
<tr>
<td>1974</td>
<td>1.55</td>
<td>17.7</td>
<td>85.6</td>
<td>144.6</td>
<td>233.0</td>
</tr>
<tr>
<td>1975</td>
<td>1.55</td>
<td>19.5</td>
<td>84.0</td>
<td>161.7</td>
<td>302.6</td>
</tr>
<tr>
<td>1976</td>
<td>1.40</td>
<td>23.2</td>
<td>86.9</td>
<td>194.8</td>
<td>327.5</td>
</tr>
<tr>
<td>1977</td>
<td>1.27</td>
<td>27.8</td>
<td>83.5</td>
<td>268.2</td>
<td>325.6</td>
</tr>
<tr>
<td>1978</td>
<td>1.23</td>
<td>32.3</td>
<td>79.7</td>
<td>369.4</td>
<td>263.0</td>
</tr>
<tr>
<td>1979</td>
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<td>35.4</td>
<td>79.1</td>
<td>434.2</td>
<td>230.8</td>
</tr>
<tr>
<td>1980</td>
<td>1.27</td>
<td>39.6</td>
<td>77.4</td>
<td>436.2</td>
<td>133.9</td>
</tr>
<tr>
<td>1981</td>
<td>1.15</td>
<td>44.7</td>
<td>78.1</td>
<td>559.9</td>
<td>166.8</td>
</tr>
<tr>
<td>1982</td>
<td>1.08</td>
<td>50.8</td>
<td>80.2</td>
<td>617.4</td>
<td>197.1</td>
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<td>1983</td>
<td>0.80</td>
<td>60.7</td>
<td>80.2</td>
<td>636.5</td>
<td>265.9</td>
</tr>
<tr>
<td>1984</td>
<td>0.56</td>
<td>72.9</td>
<td>80.2</td>
<td>748.5</td>
<td>401.9</td>
</tr>
<tr>
<td>1985</td>
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<td>100.0</td>
<td>99.3</td>
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<td>523.5</td>
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<td>672.9</td>
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<td>1987</td>
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<td>217.2</td>
<td>301.8</td>
<td>2,449.1</td>
<td>865.0</td>
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</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Urban</th>
<th>Rural</th>
<th>Total Population</th>
<th>% Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>849</td>
<td>3,032</td>
<td>3,881</td>
<td>21.9</td>
</tr>
<tr>
<td>1967</td>
<td>924</td>
<td>3,021</td>
<td>3,945</td>
<td>23.4</td>
</tr>
<tr>
<td>1968</td>
<td>1,007</td>
<td>3,073</td>
<td>4,080</td>
<td>24.7</td>
</tr>
<tr>
<td>1969</td>
<td>1,223</td>
<td>2,900</td>
<td>4,123</td>
<td>29.7</td>
</tr>
<tr>
<td>1970</td>
<td>1,309</td>
<td>2,942</td>
<td>4,251</td>
<td>30.8</td>
</tr>
<tr>
<td>1971</td>
<td>1,401</td>
<td>2,985</td>
<td>4,386</td>
<td>31.9</td>
</tr>
<tr>
<td>1972</td>
<td>1,497</td>
<td>3,030</td>
<td>4,527</td>
<td>33.1</td>
</tr>
<tr>
<td>1973</td>
<td>1,597</td>
<td>3,078</td>
<td>4,675</td>
<td>34.2</td>
</tr>
<tr>
<td>1974</td>
<td>1,700</td>
<td>3,129</td>
<td>4,829</td>
<td>35.2</td>
</tr>
<tr>
<td>1975</td>
<td>1,806</td>
<td>3,175</td>
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</tr>
<tr>
<td>1976</td>
<td>1,916</td>
<td>3,222</td>
<td>5,138</td>
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</tr>
<tr>
<td>1977</td>
<td>2,033</td>
<td>3,269</td>
<td>5,302</td>
<td>38.3</td>
</tr>
<tr>
<td>1978</td>
<td>2,153</td>
<td>3,319</td>
<td>5,472</td>
<td>39.4</td>
</tr>
<tr>
<td>1979</td>
<td>2,280</td>
<td>3,369</td>
<td>5,649</td>
<td>40.4</td>
</tr>
<tr>
<td>1980</td>
<td>2,413</td>
<td>3,421</td>
<td>5,834</td>
<td>41.4</td>
</tr>
<tr>
<td>1981</td>
<td>2,541</td>
<td>3,486</td>
<td>6,027</td>
<td>42.2</td>
</tr>
<tr>
<td>1982</td>
<td>2,696</td>
<td>3,532</td>
<td>6,228</td>
<td>43.3</td>
</tr>
<tr>
<td>1983</td>
<td>2,848</td>
<td>3,589</td>
<td>6,437</td>
<td>44.2</td>
</tr>
<tr>
<td>1984</td>
<td>3,007</td>
<td>3,650</td>
<td>6,657</td>
<td>45.2</td>
</tr>
<tr>
<td>1985</td>
<td>3,169</td>
<td>3,556</td>
<td>6,725</td>
<td>47.1</td>
</tr>
<tr>
<td>1986</td>
<td>3,340</td>
<td>3,943</td>
<td>7,283</td>
<td>45.9</td>
</tr>
<tr>
<td>1987</td>
<td>3,520</td>
<td>4,044</td>
<td>7,564</td>
<td>46.5</td>
</tr>
</tbody>
</table>

### Table 4.4. Real GDP by sector in Zambia: 1966-1987 (millions of Kwacha)

<table>
<thead>
<tr>
<th>Year</th>
<th>Urban</th>
<th>Rural</th>
<th>Total GDP</th>
<th>% Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>582</td>
<td>100</td>
<td>682</td>
<td>85.3</td>
</tr>
<tr>
<td>1967</td>
<td>618</td>
<td>99</td>
<td>717</td>
<td>86.2</td>
</tr>
<tr>
<td>1968</td>
<td>635</td>
<td>100</td>
<td>735</td>
<td>86.4</td>
</tr>
<tr>
<td>1969</td>
<td>657</td>
<td>102</td>
<td>759</td>
<td>86.6</td>
</tr>
<tr>
<td>1970</td>
<td>729</td>
<td>116</td>
<td>845</td>
<td>86.3</td>
</tr>
<tr>
<td>1971</td>
<td>725</td>
<td>118</td>
<td>843</td>
<td>86.0</td>
</tr>
<tr>
<td>1972</td>
<td>1,103</td>
<td>146</td>
<td>1,249</td>
<td>88.3</td>
</tr>
<tr>
<td>1973</td>
<td>1,093</td>
<td>144</td>
<td>1,237</td>
<td>88.4</td>
</tr>
<tr>
<td>1974</td>
<td>1,172</td>
<td>151</td>
<td>1,323</td>
<td>88.6</td>
</tr>
<tr>
<td>1975</td>
<td>1,124</td>
<td>157</td>
<td>1,281</td>
<td>87.7</td>
</tr>
<tr>
<td>1976</td>
<td>1,166</td>
<td>167</td>
<td>1,333</td>
<td>87.5</td>
</tr>
<tr>
<td>1977</td>
<td>1,260</td>
<td>168</td>
<td>1,428</td>
<td>88.2</td>
</tr>
<tr>
<td>1978</td>
<td>1,283</td>
<td>172</td>
<td>1,455</td>
<td>88.2</td>
</tr>
<tr>
<td>1979</td>
<td>1,178</td>
<td>151</td>
<td>1,329</td>
<td>88.6</td>
</tr>
<tr>
<td>1980</td>
<td>1,214</td>
<td>156</td>
<td>1,370</td>
<td>88.6</td>
</tr>
<tr>
<td>1981</td>
<td>1,173</td>
<td>172</td>
<td>1,345</td>
<td>87.2</td>
</tr>
<tr>
<td>1982</td>
<td>1,249</td>
<td>157</td>
<td>1,406</td>
<td>88.8</td>
</tr>
<tr>
<td>1983</td>
<td>1,389</td>
<td>315</td>
<td>1,704</td>
<td>81.5</td>
</tr>
<tr>
<td>1984</td>
<td>1,253</td>
<td>332</td>
<td>1,585</td>
<td>79.1</td>
</tr>
<tr>
<td>1985</td>
<td>1,357</td>
<td>344</td>
<td>1,701</td>
<td>79.8</td>
</tr>
<tr>
<td>1986</td>
<td>1,312</td>
<td>374</td>
<td>1,686</td>
<td>77.8</td>
</tr>
<tr>
<td>1987</td>
<td>1,383</td>
<td>366</td>
<td>1,749</td>
<td>79.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Firewood</th>
<th>Charcoal</th>
<th>Firewood</th>
<th>Charcoal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>80</td>
<td>161</td>
<td></td>
<td>3,763</td>
</tr>
<tr>
<td>1967</td>
<td>87</td>
<td>176</td>
<td></td>
<td>3,749</td>
</tr>
<tr>
<td>1968</td>
<td>95</td>
<td>191</td>
<td></td>
<td>3,814</td>
</tr>
<tr>
<td>1969</td>
<td>115</td>
<td>232</td>
<td></td>
<td>3,599</td>
</tr>
<tr>
<td>1970</td>
<td>123</td>
<td>249</td>
<td></td>
<td>3,651</td>
</tr>
<tr>
<td>1971</td>
<td>132</td>
<td>266</td>
<td></td>
<td>3,704</td>
</tr>
<tr>
<td>1972</td>
<td>141</td>
<td>284</td>
<td></td>
<td>3,760</td>
</tr>
<tr>
<td>1973</td>
<td>150</td>
<td>303</td>
<td></td>
<td>3,820</td>
</tr>
<tr>
<td>1974</td>
<td>160</td>
<td>323</td>
<td></td>
<td>3,883</td>
</tr>
<tr>
<td>1975</td>
<td>170</td>
<td>343</td>
<td></td>
<td>3,940</td>
</tr>
<tr>
<td>1976</td>
<td>180</td>
<td>364</td>
<td></td>
<td>3,999</td>
</tr>
<tr>
<td>1977</td>
<td>191</td>
<td>386</td>
<td></td>
<td>4,057</td>
</tr>
<tr>
<td>1978</td>
<td>202</td>
<td>409</td>
<td></td>
<td>4,119</td>
</tr>
<tr>
<td>1979</td>
<td>214</td>
<td>433</td>
<td></td>
<td>4,181</td>
</tr>
<tr>
<td>1980</td>
<td>227</td>
<td>459</td>
<td></td>
<td>4,246</td>
</tr>
<tr>
<td>1981</td>
<td>239</td>
<td>483</td>
<td></td>
<td>4,326</td>
</tr>
<tr>
<td>1982</td>
<td>253</td>
<td>512</td>
<td></td>
<td>4,383</td>
</tr>
<tr>
<td>1983</td>
<td>268</td>
<td>541</td>
<td></td>
<td>4,454</td>
</tr>
<tr>
<td>1984</td>
<td>283</td>
<td>571</td>
<td></td>
<td>4,330</td>
</tr>
<tr>
<td>1985</td>
<td>298</td>
<td>602</td>
<td></td>
<td>4,413</td>
</tr>
<tr>
<td>1986</td>
<td>314</td>
<td>635</td>
<td></td>
<td>4,893</td>
</tr>
<tr>
<td>1987</td>
<td>331</td>
<td>669</td>
<td></td>
<td>5,019</td>
</tr>
</tbody>
</table>

Source: Calculated on the basis of FAO (1986a) estimates of per capita woodfuel consumption.
Table 4.6. Variable definitions and data sources

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Data Source</th>
</tr>
</thead>
</table>
\[
\log Y_i = \beta_i + \beta_{i0} \log M + \beta_{i1} \log P_{i1} + \sum_{j \neq 1}^{n} \beta_{ij} \log P_j + \beta_{ik} \log Y_{i-1}
\]
\[
+ \beta_{il} \log I + \beta_{im} \log P + \beta_{in} \log T + E_i
\]
(4.54)

where \( T \) is a time-trend and where all the variables are as defined before. We then let the \( X \)-matrix denote the regressors so that, in econometric notation, equation (4.54) can be written as:

\[
\log Y_{ij} = \beta_{i1} + \beta_{i2} \log X_{ij2} + \beta_{i3} \log X_{ij3} + \ldots
\]
\[
+ \beta_{ik} \log X_{ijk} + U_{ij}
\]
(4.55)

where

- \( i = 1, 2 \) are sectors: rural and urban sectors.
- \( j = 1, 2, \ldots, n \) are number of observations: 22 years.
- \( k \) is number of regressors.
- \( U_{ij} \) is error term.

The actual estimation of the regression equation is, in the present study, done by the method of generalized least squares (GLS) using the PROC STEPWISE procedure of the Statistical Analysis System, SAS (SAS, 1985). In matrix form, the multivariate linear regression model in (4.56) can be represented as:

\[
Y = X\beta + U
\]
(4.56)

where

\[
Y = \begin{bmatrix}
    Y_1 \\
    Y_2 \\
    \vdots \\
    Y_n
\end{bmatrix}
\]
\[
X = \begin{bmatrix}
    1 & X_{12} & X_{13} & \ldots & X_{1k} \\
    1 & X_{22} & X_{23} & \ldots & X_{2k} \\
    \vdots & \vdots & \vdots & \ddots & \vdots \\
    1 & X_{n2} & X_{n3} & \ldots & X_{nk}
\end{bmatrix}_{nxk}
\]
\[ \beta = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_n \end{bmatrix} \quad \text{kxl} \quad \text{and} \quad U = \begin{bmatrix} U_1 \\ U_2 \\ \vdots \\ U_n \end{bmatrix} \quad \text{nxl} \]

The ordinary least squares (OLS) estimator for parameter vector \( \beta \) is:

\[ \hat{\beta} = (X'X)^{-1} X'Y \] (4.58)

The variance of \( \beta \) is:

\[ \text{var} \, (\hat{\beta}) = \sigma^2 (X'X)^{-1} \] (4.59)

The residual estimator for \( \sigma^2 \) is:

\[ \hat{\sigma}^2 = \frac{\hat{U}' \hat{U}}{n-k} \] (4.60)

where, from (4.57):

\[ \hat{U} = Y - X\hat{\beta} \] (4.61)

An important assumption of OLS is that the variance of each \( U_i \), the random variable, is the same for all values of the explanatory variable; that is:

\[ \text{var} \, (U_i) = \text{EU}_{i}^2 = \sigma^2 \] (4.62)

This is the assumption of homoskedasticity or the assumption of constant variance of the \( U_i \). If the assumption is not satisfied, then there is heteroskedasticity, that is:

\[ \text{var} \, (U_i) \neq \text{EU}_{i}^2 \neq \sigma^2 \text{ not constant} \] (4.63)
Heteroskedasticity is often encountered in econometric studies. This is the case in the present study. Residual analyses show that the assumption of constant variance does not hold in the present case.

When it exists, heteroskedasticity is considered to have two consequences on the least squares estimators: (1) the least squares estimators are unbiased but inefficient, in the statistical sense, and (2) the estimates of the variables are biased, thus distorting the tests of significance (Maddala, 1988). For these reasons, GLS is employed as a solution to the problem of heteroskedasticity.

In essence, GLS amounts to the use of transformed data, and transformation is recommended when the data set includes relatively small figures (Maddala, 1988). In this case, each $U_i$ is divided by $\delta_i$ to have a constant variance, $\var(U^*)$. That is:

$$\var(U^*) = \var\left(\frac{U_i}{\delta_i}\right) = E\left(\frac{U_i^2}{\delta_i^2}\right) - \frac{\delta_i^2}{\delta_i^2} = 1 \text{ constant} \quad (4.64)$$

Thus, the $U_i^*$ have the same variance, which is 1. The transformed model is:

$$\frac{Y_i}{\delta_i} = \beta_1 \frac{X_1}{\delta_1} + \beta_2 \left(\frac{X_2}{\delta_2}\right) + \ldots + \beta_k \left(\frac{X_k}{\delta_k}\right) + \frac{U_i}{\delta_i} \quad (4.65)$$

This procedure is known as weighted least-squares and is a special application of GLS (Koutsoyiannis, 1977). It is the procedure employed to obtain the parameter estimates of woodfuel consumption in Zambia.
CHAPTER V. DISCUSSION OF RESULTS

The full model, equation (4.54), is fitted over annual time series data for the period 1966-1987. The regressions on woodfuel consumption are disaggregated by sector: rural and urban. In turn, the regressions by sector are disaggregated by type of woodfuel: firewood and charcoal. Disaggregation by sector and type of woodfuel is done because preliminary regressions showed that sectoral woodfuel demand equations are more tractable than aggregate national woodfuel equations. In other words, national woodfuel demand coefficients conceal significant sectoral differences in woodfuel demand. This is the reason the present discussion of results focuses on demand by sector and by type of woodfuel.

Similarly, disaggregation is made for the proxy for household income. Preliminary equations were fitted employing the aggregate real GDP (Table 4.1). However, better estimates were obtained by disaggregating real GDP into rural and urban incomes (Table 4.4). Rural household income is defined as the value of agriculture, forestry and fishing; and therefore urban household income is defined as real GDP minus the value of agriculture, forestry and fishing.

Table 5.1 shows the regression equation of firewood consumption in the rural areas. The equations are obtained by employing the SAS PROC STEPWISE procedure because preliminary regressions of the full model showed a high degree of multicollinearity (SAS, 1985). The PROC STEPWISE is most helpful in this case because it gives insight into the
relationships between the independent variables (i.e., the regressors) and the dependent or response variable.

From Table 5.1, inflation (CPI) is the most significant determinant of firewood demand in the rural areas. This result also holds for charcoal, and the combined firewood and charcoal demand (Tables 5.2 and 5.3). In all these cases, inflation is by far the most significant determinant of demand for woodfuel in the rural areas.

Table 5.4 depicts the best equations selected from the PROC STEPWISE procedure. The equations are selected on the basis of goodness of fit criteria, and these criteria are: statistical significance of the coefficients at the one percent level or better, the magnitude of the $R^2$ and the adjusted $-R^2$, and the principle of parsimony (Pankratz, 1983).

The principle of parsimony is in essence a principle of thrift, and makes it possible to fit available data with only necessary coefficients. Thus, Pankratz (1983, p. 81) suggests:

The principle of parsimony is important because, in practice, parsimonious models generally produce better forecasts. The idea of parsimony gives our modeling procedure a strong practical orientation. In particular, we are not necessarily trying to find the true process responsible for generating a given realization. Rather, we are happy to find a model which only approximates the true process as long as the model explains the behavior of the available realization in a parsimonious and statistically adequate manner.

The point is, a model is an abstraction from reality, and the purpose of formulating a model is to make forecasts and to derive refutable hypotheses. These are the criteria employed in this study to choose the best equation among several regressions.
From Table 5.4, it can be seen that the coefficients on inflation are significant at better than the one percent level, and both the $R^2$ and the adjusted -$R^2$ are very high. This is not surprising, given the high levels of inflation in Zambia since the 1973 oil crisis (Table 4.2). The consumer price index (CPI) has been rising steadily since 1973, but more so during the past decade.

The high levels of inflation in Zambia can also be seen from the decline of the exchange rate of the Zambian Kwacha vis-a-vis the U.S. dollar. The exchange rate of the Kwacha has fallen from a high of K1 = $1.55 in 1974 and 1975 to K1 = $0.11 in 1987. Thus, by 1987, the Zambian Kwacha was worth only eleven cents in U.S. currency; reflecting a fall of 93% in value during the period 1975-1987.

Very high levels of inflation make substitute sources of energy unaffordable to rural households. This is why inflation has such a pervasive effect on the demand for woodfuel. The inflation coefficients are not only statistically significant at better than the one percent level, but also have plausible signs. The coefficients are positive, indicating that an increase in inflation raises woodfuel consumption among rural households.

The regression equations in Tables 5.1 to 5.4 indicate that there is insignificant correlation between woodfuel demand on one hand and income and energy prices on the other hand. One reason for this weak correlation can be the high degree of multicollinearity exhibited by the lagged model. A crucial condition for the application of the method of least squares is that the independent variables (i.e., the regressors) should
not be correlated. Otherwise the existence of multicollinearity reduces the significance of the parameter estimates (Koutsoyiannis, 1977).

However, the assumption of independence among regressors does not hold in the present study; rather, multicollinearity is a significant problem in this case. The problem of multicollinearity can be seen, for instance, from the high values of $R^2$ and adjusted $-R^2$, but very insignificant coefficients except those on inflation.

Intuitively, the existence of multicollinearity in the present study can be traced to the lagged variable, $Y_{t-1}$, the demand for woodfuel in the period previous to time $t$. As Koutsoyiannis (1977, p. 234) points out: "Naturally the successive values of a certain variable are intercorrelated, for example, income in the current period is partly determined by its own value in the previous period, and so on. Thus, multicollinearity is almost certain to exist in distributed lag models."

Koutsoyiannis (1977) also observes that multicollinearity arises from the tendency of economic variables to move together over time. Economic variables such as income, prices and investment which are included as regressors in the present study, are influenced by the same factors such as economic expansion and recession. As a result, when the determining factors such as economic expansion and recession operate, economic variables such as income, prices and investment move together over time. The economic variables show the same pattern of change over time: they tend to rise during economic expansion, and to fall during economic recession.
For these reasons, the model is reparameterized and regressed without the lagged variable, $Y_{t-1}$. Tables 5.5 to 5.7 show the results of the PROC STEPWISE regressions without the lagged variable. The tables show respectively, regressions on firewood, charcoal, and combined firewood and charcoal demand among rural households. The results in these tables are to be compared to those in Tables 5.1 to 5.3 in which the lagged variable is a regressor.

From the comparison, it is clear that the lagged variable is correlated to the structural variable growth in investment, $I$. When the lagged variable is added as a regressor in Tables 5.1 to 5.3, the structural variable is the third entry in the STEPWISE regression; it is the third most significant determinant of demand after inflation and the lagged variable. On the other hand, when the lagged variable is omitted in Tables 5.5 to 5.7, the structural variable performs poorly as a regressor. Therefore, it can be said that long-term changes in woodfuel demand depicted by $Y_{t-1}$ are correlated to changes in the structure of the economy, represented by growth in investment.

However, with and without $Y_{t-1}$ as a regressor, inflation is the most significant determinant of woodfuel demand among rural households (Table 5.4 and 5.8). On the other hand, with and without $Y_{t-1}$ as a regressor, income and energy prices are not significant determinants of woodfuel demand among rural households. This should be expected, given that woodfuel consumption in the rural areas is largely outside the monetary economy. It is estimated that, in many rural areas of developing countries, only five percent of woodfuel is purchased (Arnold and Jogma,
1977). Almost all wood for fuel is collected by family members from their own farms or from nearby customary land (French, 1985). Almost all wood is collected for own-use, and very little is traded. This explains the insignificant correlation of woodfuel consumption to income and energy prices among rural households. In addition, among rural households, woodfuel should be expected to be a good substitute for commercial energy sources such as electricity and kerosene because woodfuel has little cost in the market place, and because of the high levels of inflation, and low levels of income in the rural areas.

Given the insignificant correlation of woodfuel consumption to income and energy prices among rural households, it is not easy to conclude whether or not woodfuel is an inferior good, as studies elsewhere suggest (Anderson, 1987; Hughes-Cromwick, 1985). One definition of an inferior good is a good which a consumer buys less when the consumer’s income rises, while a normal good is one which a consumer buys more as the consumer’s income rises (Miller, 1978). Thus, the notion of an inferior good is predicated on the assumption that a given good is bought and sold in the market. But this assumption does not hold in the case of woodfuel consumption among rural households because, in the rural areas, woodfuel is almost a free good. Therefore, to understand whether or not woodfuel is an inferior good, the case in which woodfuel consumption enters the market must be considered. This is the case of woodfuel consumption in the urban areas.

Tables 5.9 to 5.11 show, respectively, the regression equations on firewood, charcoal and aggregate woodfuel consumption among urban
Table 5.1. Rural household firewood demand elasticities of lagged model
(t-ratios in parentheses)

<table>
<thead>
<tr>
<th>Model</th>
<th>Equation</th>
<th>$R^2$</th>
<th>Adj-$R^2$</th>
<th>$S^2$</th>
<th>SSE</th>
<th>Error DF</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(5.1)</td>
<td>$\log RFY = 85.292 + 0.993 \log CPI$</td>
<td>0.958</td>
<td>0.956</td>
<td>0.044</td>
<td>0.840</td>
<td>19</td>
<td>437.619</td>
</tr>
<tr>
<td>(5.2)</td>
<td>$\log RFY = 67.382 + 0.811 \log CPI + 0.187 \log RFY_{t-1}$</td>
<td>0.961</td>
<td>0.965</td>
<td>0.040</td>
<td>0.793</td>
<td>18</td>
<td>220.076</td>
</tr>
<tr>
<td>(5.3)</td>
<td>$\log RFY = 58.396 + 0.711 \log CPI + 0.280 \log RFY_{t-1} + 0.041 \log I_{t-1}$</td>
<td>0.962</td>
<td>0.955</td>
<td>0.045</td>
<td>0.772</td>
<td>17</td>
<td>142.436</td>
</tr>
<tr>
<td>(5.4)</td>
<td>$\log RFY = 60.086 + 0.768 \log CPI + 0.267 \log RFY_{t-1} + 0.042 \log I_{t-1} - 0.048 \log GDP_{t-1}$</td>
<td>0.962</td>
<td>0.953</td>
<td>0.048</td>
<td>0.766</td>
<td>16</td>
<td>101.387</td>
</tr>
<tr>
<td>(5.5)</td>
<td>$\log RFY = 55.822 + 0.709 \log CPI + 0.312 \log RFY_{t-1} + 0.054 \log I_{t-1} - 0.092 \log GDP_{t-1} + 0.063 \log OVI$</td>
<td>0.963</td>
<td>0.950</td>
<td>0.050</td>
<td>0.752</td>
<td>15</td>
<td>77.522</td>
</tr>
</tbody>
</table>
Table 5.1. Continued

\[
\begin{align*}
\log RFY &= 59.341 + 0.763 \log CPI + 0.278 \log RFY_{t-1} + 0.053 \log I \\
& \quad - 0.110 \log GDP_{t} + 0.70 \log OVI - 0.020 \log WPI \\
& \quad (2.07) \quad (2.01) \quad (0.95) \quad (0.75) \quad (-0.62) \quad (0.56) \quad (-0.28) \\
R^2 &= 0.963 \quad \text{SSE}: \quad 0.747 \\
\text{Adj-R}^2 &= 0.947 \quad \text{Error DF}: \quad 14 \\
S^2 &= 0.053 \quad \text{F-value}: \quad 60.647
\end{align*}
\]

\[
\begin{align*}
\log RFY &= 69.444 + 1.227 \log CPI + 0.187 \log RFY_{t-1} + 0.056 \log I \\
& \quad - 0.167 \log GDP_{t} + 0.061 \log OVI - 0.043 \log WPI \\
& \quad - 0.303 \log EPI \\
& \quad (1.77) \quad (0.99) \quad (0.76) \quad (-0.72) \quad (0.47) \quad (-0.46) \quad (-0.40) \\
R^2 &= 0.963 \quad \text{SSE}: \quad 0.739 \\
\text{Adj-R}^2 &= 0.944 \quad \text{Error DF}: \quad 13 \\
S^2 &= 0.057 \quad \text{F-value}: \quad 48.871
\end{align*}
\]

Definition of variables:

RFY: Rural household firewood demand in period t.
CPI: Consumer price index.
RFY\textsubscript{t-1}: Rural household firewood demand in period t-1.
I: Growth in investment.
GDP\textsubscript{t}: Rural household income.
OVI: Import unit value index of oils and fats.
WPI: Wholesale price index of wood and wood products.
EPI: Wholesale price index of electricity.
Table 5.2. Rural household charcoal demand elasticities of lagged model (t-ratios in parentheses)

<table>
<thead>
<tr>
<th>Equation</th>
<th>( R^2 )</th>
<th>Adj-( R^2 )</th>
<th>( SSE )</th>
<th>Error DF</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \log RCY = 43.171 + 0.997 \log CPI )</td>
<td>0.954</td>
<td>0.952</td>
<td>0.937</td>
<td>19</td>
<td>395.505</td>
</tr>
<tr>
<td>(207.31) (19.89)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \log RCY = 34.707 + 0.830 \log CPI + 0.173 \log RCY_{t-1} )</td>
<td>0.957</td>
<td>0.952</td>
<td>0.889</td>
<td>18</td>
<td>197.997</td>
</tr>
<tr>
<td>(4.04) (4.70) (0.99)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \log RCY = 30.490 + 0.737 \log CPI + 0.259 \log RCY_{t-1} + 0.043 \log I )</td>
<td>0.958</td>
<td>0.950</td>
<td>0.866</td>
<td>17</td>
<td>128.153</td>
</tr>
<tr>
<td>(2.84) (3.26) (1.18) (0.68)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \log RCY = 31.895 + 0.816 \log CPI + 0.241 \log RCY_{t-1} + 0.044 \log I )</td>
<td>0.958</td>
<td>0.948</td>
<td>0.854</td>
<td>16</td>
<td>91.803</td>
</tr>
<tr>
<td>- 0.067 \log GDP )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(-0.48)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \log RCY = 30.153 + 0.767 \log CPI + 0.278 \log RCY_{t-1} + 0.055 \log I )</td>
<td>0.959</td>
<td>0.945</td>
<td>0.840</td>
<td>15</td>
<td>70.001</td>
</tr>
<tr>
<td>- 0.110 \log GDP + 0.061 \log OVI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(-0.65) (0.49)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5.2. Continued

\[
\begin{align*}
\text{logRCY} &= 30.688 + 0.783 \text{logCPI} + 0.270 \text{logRCY}_{t-1} + 0.055 \text{logI} \\
&(2.30) (2.67) (1.03) (0.76) \\
-0.118 \text{logGDPl} + 0.065 \text{logOVI} - 0.009 \text{logWPI} \\
&(-0.63) (0.49) (-0.12)
\end{align*}
\]

\[R^2: 0.959 \quad \text{SSE: 0.840} \]
\[\text{Adj-R}^2: 0.941 \quad \text{Error DF: 14} \]
\[S^2: 0.060 \quad \text{F-value: 54.505} \]

\[
\begin{align*}
\text{logRCY} &= 33.006 + 0.993 \text{logCPI} + 0.234 \text{logRCY}_{t-1} + 0.057 \text{logI} \\
&(1.75) (0.81) (0.70) (0.75) \\
-0.144 \text{logGDPl} + 0.061 \text{logOVI} - 0.018 \text{logWPI} \\
&(-0.60) (0.44) (-0.20) \\
-0.144 \text{logEPI} \quad \text{(5.14)}
\end{align*}
\]

\[R^2: 0.960 \quad \text{SSE: 0.837} \]
\[\text{Adj-R}^2: 0.937 \quad \text{Error DF: 13} \]
\[S^2: 0.064 \quad \text{F-value: 43.494} \]

Definition of variables:

\[
\begin{align*}
\text{RCY:} & \quad \text{Rural household charcoal demand in period t.} \\
\text{CPI:} & \quad \text{Consumer price index.} \\
\text{RCY}_{t-1}: & \quad \text{Rural household charcoal demand in period t-1.} \\
\text{I:} & \quad \text{Growth in investment.} \\
\text{GDPl:} & \quad \text{Rural household income.} \\
\text{OVI:} & \quad \text{Import unit value index of oils and fats.} \\
\text{WPI:} & \quad \text{Wholesale price index of wood and wood products.} \\
\text{EPI:} & \quad \text{Wholesale price index of electricity.}
\end{align*}
\]
Table 5.3. Rural household aggregate woodfuel demand elasticities of lagged model (t-ratios in parentheses)

\[
\log RTY = 85.521 + 0.993 \log CPI \\
(433.49) (20.90) \\
R^2: 0.958 \quad \text{SSE: 0.841} \\
\text{Adj-R}^2: 0.956 \quad \text{Error DF: 19} \\
S^2: 0.044 \quad \text{F-value: 436.977}
\]

\[
\log RTY = 67.594 + 0.812 \log CPI + 0.186 \log RTY_{t-1} \\
(3.88) (4.45) (1.03) \\
R^2: 0.961 \quad \text{SSE: 0.794} \\
\text{Adj-R}^2: 0.956 \quad \text{Error DF: 18} \\
S^2: 0.044 \quad \text{F-value: 219.720}
\]

\[
\log RTY = 58.594 + 0.711 \log CPI + 0.280 \log RTY_{t-1} + 0.041 \log I \\
(2.65) (3.00) (1.22) (0.68) \\
R^2: 0.962 \quad \text{SSE: 0.773} \\
\text{Adj-R}^2: 0.955 \quad \text{Error DF: 17} \\
S^2: 0.046 \quad \text{F-value: 142.204}
\]

\[
\log RTY = 60.298 + 0.769 \log CPI + 0.266 \log RTY_{t-1} + 0.042 \log I \\
- 0.048 \log GDP\text{I} \\
(2.60) (2.64) (1.11) (0.67) (-0.36) \\
R^2: 0.962 \quad \text{SSE: 0.767} \\
\text{Adj-R}^2: 0.953 \quad \text{Error DF: 16} \\
S^2: 0.048 \quad \text{F-value: 101.232}
\]

\[
\log RTY = 56.036 + 0.710 \log CPI + 0.054 \log RTY_{t-1} + 0.054 \log I \\
- 0.092 \log GDP\text{I} + 0.063 \log OVI \\
(2.24) (2.24) (1.20) (0.79) (-0.58) (0.53) \\
R^2: 0.963 \quad \text{SSE: 0.753} \\
\text{Adj-R}^2: 0.950 \quad \text{Error DF: 15} \\
S^2: 0.050 \quad \text{F-value: 77.399}
\]
Table 5.3. Continued

\[
\log RTY = 59.503 + 0.763 \log CPI + 0.278 \log RTY_{t-1} + 0.053 \log I \\
(2.07) (2.01) (0.95) (0.75)
\]

\[
- 0.110 \log GDP_{t} + 0.070 \log OVI - 0.020 \log WPI \\
(-0.62) (0.56) (-0.28)
\]

\[ R^2: 0.963 \]
\[ \text{SSE: 0.749} \]
\[ \text{Adj-R}^2: 0.947 \]
\[ \text{Error DF: 14} \]
\[ S: 0.054 \]
\[ F-value: 60.545 \]

\[
\log RTY = 69.501 + 1.222 \log CPI + 0.187 \log RTY_{t-1} + 0.056 \log I \\
(1.77) (0.99) (0.49) (0.76)
\]

\[
- 0.166 \log GDP_{t} + 0.061 \log OVI - 0.043 \log WPI - 0.300 \log EPI \\
(-0.72) (0.47) (-0.46) (-0.39)
\]

\[ R^2: 0.963 \]
\[ \text{SSE: 0.740} \]
\[ \text{Adj-R}^2: 0.944 \]
\[ \text{Error DF: 13} \]
\[ S: 0.057 \]
\[ F-value: 48.776 \]

Definition of variables:

RTY: Rural household aggregate woodfuel demand in period t.

CPI: Consumer price index.

RTY\_t-1: Rural household aggregate woodfuel demand in period t-1.

I: Growth in investment.

GDP\_t: Rural household income.

OVI: Import unit value index of oils and fats.

WPI: Wholesale price index of wood and wood products.

EPI: Wholesale price index of electricity.
Table 5.4. Rural household woodfuel demand elasticities of lagged model: selected equations (t-ratios in parentheses)

<table>
<thead>
<tr>
<th>Equation</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>R^2</th>
<th>SSE</th>
<th>Adj-R^2</th>
<th>Adj-R^2 SE</th>
<th>Error DF</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Firewood demand equation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firewood demand equation</td>
<td></td>
<td>85.292</td>
<td>0.993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>logRFY = 85.292 + 0.993 logCPI</td>
<td>(432.69)</td>
<td>(20.92)</td>
<td></td>
<td>0.958</td>
<td>0.840</td>
<td>0.956</td>
<td>0.044</td>
<td>19</td>
<td>437.619</td>
</tr>
<tr>
<td><strong>Charcoal demand equation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charcoal demand equation</td>
<td></td>
<td>43.171</td>
<td>0.997</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>logRCY = 43.171 + 0.997 logCPI</td>
<td>(207.31)</td>
<td>(19.89)</td>
<td></td>
<td>0.954</td>
<td>0.937</td>
<td>0.952</td>
<td>0.049</td>
<td>19</td>
<td>395.505</td>
</tr>
<tr>
<td><strong>Aggregate woodfuel demand equation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate woodfuel demand equation</td>
<td></td>
<td>85.521</td>
<td>0.993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>logRTY = 85.521 + 0.993 logCPI</td>
<td>(433.49)</td>
<td>(20.90)</td>
<td></td>
<td>0.958</td>
<td>0.841</td>
<td>0.956</td>
<td>0.044</td>
<td>19</td>
<td>436.977</td>
</tr>
</tbody>
</table>

Definition of variables:

RFY: Rural household firewood demand in period t.
RCY: Rural household charcoal demand in period t.
RTY: Rural household aggregate fuelwood demand in period t.
CPI: Consumer price index.
Table 5.5. Rural household firewood demand elasticities of unlagged model (t-ratios in parentheses)

<table>
<thead>
<tr>
<th>Model</th>
<th>Equation</th>
<th>R²</th>
<th>Adj-R²</th>
<th>S²</th>
<th>SSE</th>
<th>Error DF</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\log \text{RFY} = 85.292 + 0.993 \log \text{CPI}$</td>
<td>0.958</td>
<td>0.956</td>
<td>0.044</td>
<td>0.840</td>
<td>19</td>
<td>437.619</td>
</tr>
<tr>
<td>2</td>
<td>$\log \text{RFY} = 85.646 + 1.010 \log \text{CPI} - 0.317 \log \text{WPI}$</td>
<td>0.959</td>
<td>0.955</td>
<td>0.046</td>
<td>0.824</td>
<td>18</td>
<td>211.269</td>
</tr>
<tr>
<td>3</td>
<td>$\log \text{RFY} = 86.417 + 1.093 \log \text{CPI} - 0.038 \log \text{WPI} - 0.086 \log \text{GDP}_1$</td>
<td>0.960</td>
<td>0.953</td>
<td>0.047</td>
<td>0.804</td>
<td>17</td>
<td>136.588</td>
</tr>
<tr>
<td>4</td>
<td>$\log \text{RFY} = 87.565 + 1.509 \log \text{CPI} - 0.065 \log \text{WPI} - 0.139 \log \text{GDP}_1 - 0.362 \log \text{EPI}$</td>
<td>0.962</td>
<td>0.952</td>
<td>0.049</td>
<td>0.777</td>
<td>16</td>
<td>99.923</td>
</tr>
<tr>
<td>5</td>
<td>$\log \text{RFY} = 88.350 + 1.717 \log \text{CPI} - 0.065 \log \text{WPI} - 0.180 \log \text{GDP}_1 - 0.532 \log \text{EPI} + 0.036 \log i$</td>
<td>0.962</td>
<td>0.950</td>
<td>0.051</td>
<td>0.759</td>
<td>15</td>
<td>76.740</td>
</tr>
</tbody>
</table>
Table 5.5. Continued

\[
\log RFY = 88.511 + 1.717 \log CPI - 0.0728 \log WPI - 0.217 \log GDP1 \\
\quad - 0.532 \log EPI + 0.041 \log I + 0.044 \log OVI \\
\quad (34.09) (2.44) (-1.03) (-1.08) (5.30) (-0.90) (0.63) (0.36)
\]

\[ R^2: \quad 0.963 \quad \text{SSE:} \quad 0.752 \]
\[ \text{Adj-R}^2: \quad 0.947 \quad \text{Error DF:} \quad 14 \]
\[ S^2: \quad 0.054 \quad \text{F-value:} \quad 60.255 \]

Definition of variables:

- **RFY**: Rural household firewood demand in period t.
- **CPI**: Consumer price index.
- **WPI**: Wholesale price index of wood and wood products.
- **GDP1**: Rural household income.
- **EPI**: Wholesale price index of electricity.
- **I**: Growth in investment.
- **OVI**: Import unit value index of oils and fats.
Table 5.6. Rural household charcoal demand elasticities of unlagged model (t-ratios in parentheses)

<table>
<thead>
<tr>
<th>Model</th>
<th>Equation</th>
<th>( R^2 )</th>
<th>( \text{Adj-R}^2 )</th>
<th>( S^2 )</th>
<th>SSE</th>
<th>Error DF</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(5.31)</td>
<td>( \text{logRCY} = 43.171 + 0.997 \text{logCPI} )</td>
<td>0.954</td>
<td>0.952</td>
<td>0.049</td>
<td>0.937</td>
<td>19</td>
<td>395.505</td>
</tr>
<tr>
<td>(5.32)</td>
<td>( \text{logRCY} = 43.891 + 1.080 \text{logCPI} - 0.090 \text{logGDPl} )</td>
<td>0.955</td>
<td>0.950</td>
<td>0.051</td>
<td>0.914</td>
<td>18</td>
<td>192.295</td>
</tr>
<tr>
<td>(5.33)</td>
<td>( \text{logRCY} = 44.532 + 1.350 \text{logCPI} - 0.121 \text{logGDPl} - 0.242 \text{EPI} )</td>
<td>0.956</td>
<td>0.948</td>
<td>0.053</td>
<td>0.901</td>
<td>17</td>
<td>122.947</td>
</tr>
<tr>
<td>(5.34)</td>
<td>( \text{logRCY} = 45.181 + 1.461 \text{logCPI} - 0.143 \text{logGDPl} - 0.316 \text{EPI} - 0.031 \text{logWPI} )</td>
<td>0.957</td>
<td>0.946</td>
<td>0.056</td>
<td>0.888</td>
<td>16</td>
<td>88.134</td>
</tr>
<tr>
<td>(5.35)</td>
<td>( \text{logRCY} = 45.910 + 1.654 \text{logCPI} - 0.182 \text{logGDPl} - 0.474 \text{EPI} - 0.044 \text{logWPI} + 0.034 \text{logI} )</td>
<td>0.957</td>
<td>0.943</td>
<td>0.0582</td>
<td>0.872</td>
<td>15</td>
<td>67.294</td>
</tr>
</tbody>
</table>
Table 5.6. Continued

\[
\log \text{RCY} = 46.034 + 1.654 \log \text{CPI} - 0.210 \log \text{GDPl} - 0.474 \text{EPI} \\
(16.50) \quad (2.18) \quad (-0.97) \quad (-0.75) \\
- 0.050 \log \text{GDPl} + 0.038 \log I + 0.034 \log \text{OVI} \quad (5.37) \\
(-0.66) \quad (0.54) \quad (0.26)
\]

- \text{R}^2: 0.958 \quad \text{SSE:} 0.868 \\
- \text{Adj-R}^2: 0.939 \quad \text{Error DF:} 14 \\
- \text{S}: 0.062 \quad \text{F-value:} 52.596

Definition of variables:

- \text{RCY}: Rural household charcoal demand in period t.
- \text{CPI}: Consumer price index.
- \text{WPI}: Wholesale price index of wood and wood products.
- \text{GDPl}: Rural household income.
- \text{EPI}: Wholesale price index of electricity.
- \text{I}: Growth in investment.
- \text{OVI}: Import unit value index of oils and fats.
Table 5.7. Rural household aggregate woodfuel demand elasticities of unlagged model (t-ratios in parentheses)

<table>
<thead>
<tr>
<th>Equation</th>
<th>Coefficients</th>
<th>t-ratios</th>
<th>R²</th>
<th>Adj-R²</th>
<th>S²</th>
<th>F-value</th>
<th>Error DF</th>
<th>SSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \log RTY = 85.521 + 0.993 \log CPI )</td>
<td>83.49</td>
<td>20.90</td>
<td>0.958</td>
<td>0.956</td>
<td>0.044</td>
<td>436.977</td>
<td>19</td>
<td>0.841</td>
</tr>
<tr>
<td>( \log RFY = 85.871 + 1.010 \log CPI - 0.031 \log WPI )</td>
<td>132.39</td>
<td>17.85</td>
<td>(-0.57)</td>
<td>0.959</td>
<td>0.955</td>
<td>0.046</td>
<td>210.869</td>
<td>18</td>
</tr>
<tr>
<td>( \log RTY = 86.643 + 1.093 \log CPI - 0.038 \log WPI - 0.087 \log GDP1 )</td>
<td>64.69</td>
<td>7.90</td>
<td>(-0.67)</td>
<td>0.960</td>
<td>0.953</td>
<td>0.047</td>
<td>136.388</td>
<td>17</td>
</tr>
<tr>
<td>( \log RTY = 87.78565 + 1.5089 \log CPI - 0.051 \log WPI - 0.139 \log GDP1 - 0.361 \log EPI )</td>
<td>42.81</td>
<td>2.63</td>
<td>(-0.85)</td>
<td>0.961</td>
<td>0.952</td>
<td>0.049</td>
<td>99.718</td>
<td>16</td>
</tr>
<tr>
<td>( \log RTY = 88.574 + 1.716 \log CPI - 0.065 \log WPI - 0.180 \log GDP1 - 0.531 \log EPI + 0.036 \log i )</td>
<td>35.65</td>
<td>2.51</td>
<td>(-1.07)</td>
<td>0.962</td>
<td>0.950</td>
<td>0.051</td>
<td>76.574</td>
<td>15</td>
</tr>
</tbody>
</table>
Table 5.7. Continued

\[
\log\text{RTY} = 88.734 + 1.716 \log\text{CPI} - 0.071 \log\text{WPI} - 0.217 \log\text{GDPl} - 0.531 \log\text{EPI} + 0.041 \log\text{I} + 0.044 \log\text{OVI}
\]

\[
(34.13) \quad (2.43) \quad (-1.02) \quad (-1.07) \quad (-0.90) \quad (0.63) \quad (0.36)
\]

$R^2$: 0.963 \quad SSE: 0.754
Adj-$R^2$: 0.947 \quad Error DF: 14
$S^2$: 0.054 \quad F-value: 60.119

Definition of variables:

RTY: Rural household firewood demand in period t.
CPI: Consumer price index.
WPI: Wholesale price index of wood and wood products.
GDPl: Rural household income.
EPI: Wholesale price index of electricity.
I: Growth in investment.
OVI: Import unit value index of oils and fats.
Table 5.8. Rural household woodfuel demand elasticities of unlagged model: selected equations (t-ratios in parentheses)

<table>
<thead>
<tr>
<th>Demand Equation</th>
<th>Coefficients</th>
<th>t-ratios</th>
<th>R^2</th>
<th>Adj-R^2</th>
<th>SSE</th>
<th>Error DF</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firewood demand equation</td>
<td>( \log RFY = 85.292 + 0.993 \log CPI )</td>
<td>( t = 432.69 ) ( t = 20.92 )</td>
<td>0.958</td>
<td>0.956</td>
<td>0.840</td>
<td>19</td>
<td>437.619</td>
</tr>
<tr>
<td>Charcoal demand equation</td>
<td>( \log RCY = 43.171 + 0.997 \log CPI )</td>
<td>( t = 207.31 ) ( t = 19.89 )</td>
<td>0.954</td>
<td>0.952</td>
<td>0.937</td>
<td>19</td>
<td>395.505</td>
</tr>
<tr>
<td>Aggregate woodfuel demand equation</td>
<td>( \log RTY = 85.521 + 0.993 \log CPI )</td>
<td>( t = 433.49 ) ( t = 20.90 )</td>
<td>0.958</td>
<td>0.956</td>
<td>0.841</td>
<td>19</td>
<td>436.977</td>
</tr>
</tbody>
</table>

Definition of variables:

- RFY: Rural household firewood demand in period t.
- RCY: Rural household charcoal demand in period t.
- RTY: Rural household aggregate woodfuel demand in period t.
- CPI: Consumer price index.
households. The equations are generated by PROC STEPWISE regression with the lagged variable, $Y_{t-1}$, included as a regressor. Table 5.12 shows the best equations in each case chosen from this procedure.

From Table 5.12, it is clear that the coefficients on the lagged variable are significant at the better than the one percent level, and both the $R^2$ and the adjusted $R^2$ are very high. This case is different from that of rural households where inflation is the most significant determinant of demand even when the lagged variable is included as a regressor. But the difference is to be expected because rural and urban households face different circumstances in the supply and demand for woodfuel. In the case of rural households, woodfuel is almost a free good. In the case of urban households, woodfuel is bought and sold in the market place. Therefore, significant sectoral differences in woodfuel demand are to be expected.

Tables 5.13 to 5.15 show, respectively, the regression equations on firewood, charcoal, and aggregate woodfuel consumption by urban households when the lagged variable is not included as a regressor. As in the case of the rural sector, the exclusion of the lagged variable from the regressions on urban woodfuel demand reduces the degree of multicollinearity. Thus, the results documented in Tables 5.13 to 5.15 are more tractable than any other that this study has generated. Table 5.16 summarizes the equations which satisfy the goodness of performance criteria as the best equations from Tables 5.13 to 5.15.

The equations in Table 5.16 indicate that demand for woodfuel by urban households is a function of inflation (CPI), income (GDP2), and
Table 5.9. Urban household firewood demand elasticities of lagged model
(t-ratios in parentheses)

\[
\log (UFY) = 0.694 + 0.926 \log (UFY)_{t-1} \quad (5.47)
\]

- \( R^2: 0.996 \)
- Adj-R\(^2\): 0.996
- \( S^2: 0.003 \)
- \( \text{F-value}: 5051.464 \)
- \( \text{Error DF}: 19 \)
- \( \text{SSE}: 0.065 \)

\[
\log (UFY) = 1.004 + 0.878 \log (UFY)_{t-1} + 0.052 \log (EPI) \quad (5.48)
\]

- \( R^2: 0.997 \)
- Adj-R\(^2\): 0.996
- \( S^2: 0.003 \)
- \( \text{F-value}: 2728.037 \)
- \( \text{Error DF}: 18 \)
- \( \text{SSE}: 0.056 \)

\[
\log (UFY) = 1.060 + 0.868 \log (UFY)_{t-1} + 0.067 \log (EPI) - 0.019 \log (I) \quad (5.49)
\]

- \( R^2: 0.997 \)
- Adj-R\(^2\): 0.997
- \( S^2: 0.003 \)
- \( \text{F-value}: 1951.274 \)
- \( \text{Error DF}: 17 \)
- \( \text{SSE}: 0.050 \)

\[
\log (UFY) = 1.075 + 0.876 \log (UFY)_{t-1} + 0.075 \log (EPI) - 0.020 \log (I) - 0.020 \log (OVI) \quad (5.50)
\]

- \( R^2: 0.997 \)
- Adj-R\(^2\): 0.997
- \( S^2: 0.003 \)
- \( \text{F-value}: 1440.508 \)
- \( \text{Error DF}: 16 \)
- \( \text{SSE}: 0.048 \)

\[
\log (UFY) = 1.229 + 0.862 \log (UFY)_{t-1} + 0.087 \log (EPI) - 0.020 \log (I) - 0.015 \log (OVI) - 0.007 \log (WPI) \quad (5.51)
\]

- \( R^2: 0.997 \)
- Adj-R\(^2\): 0.996
- \( S^2: 0.003 \)
- \( \text{F-value}: 1085.988 \)
- \( \text{Error DF}: 15 \)
- \( \text{SSE}: 0.047 \)
Table 5.9. Continued

\[
\begin{align*}
\log UF_Y &= 1.288 + 0.876 \log UF_{Y,t-1} + 0.079 \log EPI - 0.020 \log I \\
&\quad - 0.015 \log OVI - 0.006 \log WPI - 0.009 \log GDP^2 \\
&\quad (1.82) \quad (8.91) \quad (1.06) \quad (-1.44) \quad (-0.45) \quad (-0.24) \quad (-0.18) \\
R^2 &= 0.997 \\
\text{Adj-R}^2 &= 0.996 \\
S^2 &= 0.003 \\
\text{SSE} &= 0.047 \\
\text{Error DF} &= 14 \\
F-value &= 846.640
\end{align*}
\]

\[
\begin{align*}
\log UF_Y &= 1.339 + 0.873 \log UF_{Y,t-1} + 0.068 \log EPI - 0.019 \log I \\
&\quad - 0.014 \log OVI - 0.007 \log WPI - 0.008 \log GDP^2 \\
&\quad (1.48) \quad (8.09) \quad (0.49) \quad (-1.29) \quad (-0.45) \quad (-0.25) \quad (-0.16) \\
&\quad + 0.015 \log CPI \\
&\quad (0.10) \\
R^2 &= 0.997 \\
\text{Adj-R}^2 &= 0.996 \\
S^2 &= 0.004 \\
\text{SSE} &= 0.047 \\
\text{Error DF} &= 13 \\
F-value &= 674.360
\end{align*}
\]

**Definition of variables:**

- **UFY:** Urban household firewood demand in period t.
- **UFYt-1:** Urban household firewood demand in period t-1.
- **EPI:** Wholesale price index of electricity.
- **I:** Growth in investment.
- **OVI:** Import unit value index of oils and fats.
- **WPI:** Wholesale price index of wood and wood products.
- **GDPI:** Rural household income.
- **CPI:** Consumer price index.
Table 5.10. Urban household charcoal demand elasticities of lagged model (t-ratios in parentheses)

\[
\log \text{UCY} = 0.775 + 0.926 \log \text{UCY}_{t-1} \\
(4.06) (69.49)
\]

\[
R^2: 0.996 \quad \text{SSE: 0.060} \\
\text{Adj-R}^2: 0.996 \quad \text{Error DF: 19} \\
S^2: 0.004 \quad \text{F-value: 4829.376}
\]

\[
\log \text{UCY} = 1.182 + 0.876 \log \text{UCY}_{t-1} + 0.054 \log \text{EPI} \\
(3.81) (26.34) (1.63)
\]

\[
R^2: 0.997 \quad \text{SSE: 0.059} \\
\text{Adj-R}^2: 0.997 \quad \text{Error DF: 18} \\
S^2: 0.003 \quad \text{F-value: 2625.101}
\]

\[
\log \text{UCY} = 1.257 + 0.865 \log \text{UCY}_{t-1} + 0.070 \log \text{EPI} - 0.020 \log I \\
(4.14) (26.32) (2.05) (-1.51)
\]

\[
R^2: 0.997 \quad \text{SSE: 0.052} \\
\text{Adj-R}^2: 0.997 \quad \text{Error DF: 17} \\
S^2: 0.003 \quad \text{F-value: 1875.785}
\]

\[
\log \text{UCY} = 1.259 + 0.872 \log \text{UCY}_{t-1} + 0.077 \log \text{EPI} - 0.020 \log I \\
- 0.018 \log \text{OVI} \\
(4.20) (25.28) (2.17) (-1.53) (-0.79)
\]

\[
R^2: 0.997 \quad \text{SSE: 0.050} \\
\text{Adj-R}^2: 0.996 \quad \text{Error DF: 16} \\
S^2: 0.003 \quad \text{F-value: 1376.211}
\]

\[
\log \text{UCY} = 1.508 + 0.854 \log \text{UCY}_{t-1} + 0.094 \log \text{EPI} - 0.020 \log I \\
- 0.012 \log \text{OVI} - 0.010 \log \text{WPI} \\
(2.10) (14.17) (1.63) (-1.48) (-0.41) (-0.39)
\]

\[
R^2: 0.997 \quad \text{SSE: 0.049} \\
\text{Adj-R}^2: 0.996 \quad \text{Error DF: 15} \\
S^2: 0.003 \quad \text{F-value: 1042.406}
\]
Table 5.10. Continued

\[
\log \text{UCY} = 1.513 + 0.856 \log \text{UCY}_{t-1} + 0.093 \log \text{EPI} - 0.020 \log I
\]

\[
\text{Adj-R}^2: 0.996 \quad \text{Error DF: } 14 \quad \text{F-value: } 645.343
\]

\[
\log \text{UCY} = 1.523 + 0.855 \log \text{UCY}_{t-1} + 0.091 \log \text{EPI} - 0.020 \log I
\]

\[
\text{Adj-R}^2: 0.996 \quad \text{Error DF: } 13 \quad \text{F-value: } 645.343
\]

Definition of variables:

UCY: Urban household charcoal demand in period t.

UCY_{t-1}: Urban household charcoal demand in period t-1.

EPI: Wholesale price index of electricity.

I: Growth in investment.

OVI: Import unit value index of oils and fats.

WPI: Wholesale price index of wood and wood products.

GDPl: Rural household income.

CPI: Consumer price index.
Table 5.11. Urban household aggregate woodfuel demand elasticities of lagged model (t-ratios in parentheses)

<table>
<thead>
<tr>
<th>Equation</th>
<th>Coefficients</th>
<th>t-values</th>
<th>R-squared</th>
<th>Adjusted R-squared</th>
<th>Error DF</th>
<th>F-value</th>
<th>SSE</th>
<th>Adj-R-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \log UTY = 0.814 + 0.926 \log UTY_{t-1} )</td>
<td>(4.02) (70.09)</td>
<td>0.996</td>
<td>0.004</td>
<td>0.996</td>
<td>19</td>
<td>4912.856</td>
<td>0.066</td>
<td>0.996</td>
</tr>
<tr>
<td>( \log UTY = 1.265 + 0.877 \log UTY_{t-1} + 0.054 \log EPI )</td>
<td>(3.72) (26.55) (1.61)</td>
<td>0.997</td>
<td>0.003</td>
<td>0.997</td>
<td>18</td>
<td>2665.309</td>
<td>0.058</td>
<td>0.996</td>
</tr>
<tr>
<td>( \log UTY = 1.350 + 0.866 \log UTY_{t-1} + 0.068 \log EPI - 0.020 \log I )</td>
<td>(4.05) (26.54) (2.04) (-1.52)</td>
<td>0.997</td>
<td>0.003</td>
<td>0.997</td>
<td>17</td>
<td>1905.72</td>
<td>0.051</td>
<td>0.996</td>
</tr>
<tr>
<td>( \log UTY = 1.344 + 0.874 \log UTY_{t-1} + 0.076 \log EPI - 0.020 \log I - 0.018 \log OVI )</td>
<td>(3.99) (25.52) (2.16) (-1.54) (-0.81)</td>
<td>0.997</td>
<td>0.003</td>
<td>0.997</td>
<td>16</td>
<td>1401.126</td>
<td>0.049</td>
<td>0.996</td>
</tr>
<tr>
<td>( \log UTY = 1.585 + 0.857 \log UTY_{t-1} + 0.092 \log EPI - 0.020 \log I - 0.013 \log OVI - 0.009 \log WPI )</td>
<td>(2.06) (14.32) (1.60) (-1.49) (-0.44) (-0.35)</td>
<td>0.997</td>
<td>0.003</td>
<td>0.997</td>
<td>15</td>
<td>1059.444</td>
<td>0.049</td>
<td>0.996</td>
</tr>
</tbody>
</table>
Table 5.11. Continued

\[
\log \text{UTY} = 1.594 + 0.863 \log \text{UTY}_{t-1} + 0.088 \log \text{EPI} - 0.020 \log I
\]
\[
(1.98) \quad (8.71) \quad (1.18) \quad (-1.44)
\]
\[
- 0.012 \log \text{OVI} - 0.009 \log \text{WPI} - 0.004 \log \text{GDP2}
\]
\[
(-0.40) \quad (-0.32) \quad (-0.08)
\]
\[
R^2: \quad 0.997 \quad \text{SSE:} \quad 0.049
\]
\[
\text{Adj-R}^2: \quad 0.996 \quad \text{Error DF:} \quad 14
\]
\[
S^2: \quad 0.004 \quad \text{F-value:} \quad 834.368
\]

\[
\log \text{UTY} = 1.621 + 0.861 \log \text{UTY}_{t-1} + 0.083 \log \text{EPI} - 0.020 \log I
\]
\[
(1.55) \quad (7.93) \quad (0.60) \quad (-1.31)
\]
\[
- 0.013 \log \text{OVI} - 0.009 \log \text{WPI} - 0.004 \log \text{GDP2}
\]
\[
(-0.30) \quad (-0.30) \quad (-0.07)
\]
\[
+ 0.007 \log \text{CPI}
\]
\[
(0.04)
\]
\[
R^2: \quad 0.997 \quad \text{SSE:} \quad 0.049
\]
\[
\text{Adj-R}^2: \quad 0.996 \quad \text{Error DF:} \quad 13
\]
\[
S^2: \quad 0.004 \quad \text{F-value:} \quad 656.223
\]

Definition of variables:

\text{UTY}: \quad \text{Urban household charcoal demand in period } t. \\
\text{UTY}_{t-1}: \quad \text{Urban household charcoal demand in period } t-1. \\
\text{EPI}: \quad \text{Wholesale price index of electricity.} \\
I: \quad \text{Growth in investment.} \\
\text{OVI}: \quad \text{Import unit value index of oils and fats.} \\
\text{WPI}: \quad \text{Wholesale price index of wood and wood products.} \\
\text{GDP2}: \quad \text{Rural household income.} \\
\text{CPI}: \quad \text{Consumer price index.}
Table 5.12. Urban household woodfuel demand elasticities of lagged model: selected equations (t-ratios in parentheses)

<table>
<thead>
<tr>
<th>Woodfuel Demand Equation</th>
<th>Coefficients</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firewood demand equation</td>
<td>( \log UFY = 0.694 + 0.926 \log UFY_{t-1} )</td>
<td>(4.21) (71.07)</td>
</tr>
<tr>
<td>R(^2):</td>
<td>0.996</td>
<td>SSE: 0.065</td>
</tr>
<tr>
<td>Adj-R(^2):</td>
<td>0.996</td>
<td>Error DF: 19</td>
</tr>
<tr>
<td>S(^2):</td>
<td>0.003</td>
<td>F-value: 5051.464</td>
</tr>
<tr>
<td>Charcoal demand equation</td>
<td>( \log UCY = 0.775 + 0.926 \log UCY_{t-1} )</td>
<td>(4.06) (69.49)</td>
</tr>
<tr>
<td>R(^2):</td>
<td>0.996</td>
<td>SSE: 0.060</td>
</tr>
<tr>
<td>Adj-R(^2):</td>
<td>0.996</td>
<td>Error DF: 19</td>
</tr>
<tr>
<td>S(^2):</td>
<td>0.004</td>
<td>F-value: 4829.376</td>
</tr>
<tr>
<td>Aggregate woodfuel demand equation</td>
<td>( \log UTY = 0.814 + 0.926 \log UTY_{t-1} )</td>
<td>(4.02) (70.09)</td>
</tr>
<tr>
<td>R(^2):</td>
<td>0.996</td>
<td>SSE: 0.066</td>
</tr>
<tr>
<td>Adj-R(^2):</td>
<td>0.996</td>
<td>Error DF: 19</td>
</tr>
<tr>
<td>S(^2):</td>
<td>0.004</td>
<td>F-value: 4912.856</td>
</tr>
</tbody>
</table>

Definition of variables:
- UFY: Urban household firewood demand in period t.
- UFY\(_{t-1}\): Urban household firewood demand in period t-1.
- UCY: Urban household charcoal demand in period t.
- UCY\(_{t-1}\): Urban household charcoal demand in period t-1.
- UTY: Urban household charcoal demand in period t.
- UTY\(_{t-1}\): Urban household charcoal demand in period t-1.
Table 5.13. Urban household firewood demand elasticities of unlagged model (t-ratios in parentheses)

<table>
<thead>
<tr>
<th>Model</th>
<th>Equation</th>
<th>R^2</th>
<th>Adj-R^2</th>
<th>S^2</th>
<th>SSE</th>
<th>Error DF</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(5.71)</td>
<td>$\log UFY = 8.851 + 0.873 \log CPI$</td>
<td>0.868</td>
<td>0.861</td>
<td>0.120</td>
<td>2.282</td>
<td>19</td>
<td>124.362</td>
</tr>
<tr>
<td>(5.72)</td>
<td>$\log UFY = -1.004 + 0.878 \log CPI + 0.457052 \log GDP2$</td>
<td>0.963</td>
<td>0.959</td>
<td>0.035</td>
<td>0.632</td>
<td>18</td>
<td>236.300</td>
</tr>
<tr>
<td>(5.73)</td>
<td>$\log UFY = 4.572 + 0.762 \log CPI + 0.305 \log GDP2 - 0.182 \log WPI$</td>
<td>0.982</td>
<td>0.979</td>
<td>0.018</td>
<td>0.306</td>
<td>17</td>
<td>313.134</td>
</tr>
<tr>
<td>(5.74)</td>
<td>$\log UFY = 3.714 + 0.491 \log CPI + 0.302 \log GDP2 - 0.169 \log WPI + 0.254 \log EPI$</td>
<td>0.983</td>
<td>0.979</td>
<td>0.018</td>
<td>0.290</td>
<td>16</td>
<td>233.457</td>
</tr>
<tr>
<td>(5.75)</td>
<td>$\log UFY = 3.575 + 0.446 \log CPI + 0.321 \log GDP2 - 0.165 \log WPI + 0.300 \log EPI - 0.015 \log I$</td>
<td>0.983</td>
<td>0.978</td>
<td>0.019</td>
<td>0.286</td>
<td>15</td>
<td>177.448</td>
</tr>
</tbody>
</table>
Table 5.13. Continued

<table>
<thead>
<tr>
<th>logUFY = 3.678 + 0.424 logCPI + 0.313 logGDP2 - 0.169 logWPI + 0.317 logEPI - 0.016 log(I) + 0.016 logOVI</th>
<th>R(^2): 0.983</th>
<th>SSE: 0.285</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1.82) (1.22) (4.14) (-3.22) (1.00) (-0.44) (0.21)</td>
<td>Adj-R(^2): 0.976</td>
<td>Error DF: 14</td>
</tr>
<tr>
<td>S(_\text{e}): 0.020</td>
<td>F-value: 138.449</td>
<td></td>
</tr>
</tbody>
</table>

Definition of variables:

UFY: Urban household firewood demand in period t.
CPI: Consumer price index.
GDP2: Wholesale price index of electricity.
WPI: Wholesale price index of wood and wood products.
EPI: Wholesale price index of electricity.
I: Growth in investment.
OVI: Import unit value index of oils and fats.
Table 5.14. Urban household charcoal demand elasticities of unlagged model (t-ratios in parentheses)

\[
\begin{align*}
\text{logUCY} &= 10.489 + 0.872 \text{logCPI} \\
& \quad (32.26) (11.14) \\
& \quad (5.81) \\
R^2 &= 0.867 \quad \text{SSE:} \quad 2.283 \\
\text{Adj-R}^2 &= 0.860 \quad \text{Error DF:} \quad 19 \\
S^2 &= 0.120 \quad \text{F-value:} \quad 124.110
\end{align*}
\]

\[
\begin{align*}
\text{logUCY} &= 1.020 + 0.560 \text{logCPI} + 0.457 \text{logGDP2} \\
& \quad (0.73) (9.01) (6.86) \\
& \quad (5.82) \\
R^2 &= 0.963 \quad \text{SSE:} \quad 0.632 \\
\text{Adj-R}^2 &= 0.959 \quad \text{Error DF:} \quad 18 \\
S^2 &= 0.035 \quad \text{F-value:} \quad 235.916
\end{align*}
\]

\[
\begin{align*}
\text{logUCY} &= 6.212 + 0.761 \text{logCPI} + 0.305 \text{logGDP2} - 0.182 \text{logWPI} \\
& \quad (3.95) (11.74) (5.14) (-4.26) \\
& \quad (5.83) \\
R^2 &= 0.982 \quad \text{SSE:} \quad 0.306 \\
\text{Adj-R}^2 &= 0.979 \quad \text{Error DF:} \quad 17 \\
S^2 &= 0.018 \quad \text{F-value:} \quad 313.298
\end{align*}
\]

\[
\begin{align*}
\text{logUCY} &= 5.301 + 0.474 \text{logCPI} + 0.321 \text{logGDP2} - 0.168 \text{logWPI} + 0.270 \text{logEPI} \\
& \quad (2.92) (1.62) (5.22) (-3.76) (1.00) \\
& \quad (5.84) \\
R^2 &= 0.983 \quad \text{SSE:} \quad 0.288 \\
\text{Adj-R}^2 &= 0.979 \quad \text{Error DF:} \quad 16 \\
S^2 &= 0.018 \quad \text{F-value:} \quad 235.287
\end{align*}
\]

\[
\begin{align*}
\text{logUCY} &= 5.156 + 0.430 \text{logCPI} + 0.322 \text{logGDP2} - 0.164 \text{logWPI} + 0.318 \text{logEPI} - 0.016 \text{logI} \\
& \quad (2.73) (1.34) (5.10) (-3.51) (-0.47) \\
& \quad (5.85) \\
R^2 &= 0.983 \quad \text{SSE:} \quad 0.283 \\
\text{Adj-R}^2 &= 0.978 \quad \text{Error DF:} \quad 15 \\
S^2 &= 0.019 \quad \text{F-value:} \quad 179.058
\end{align*}
\]
Table 5.14. Continued

\[
\begin{align*}
\log UCY &= 5.271 + 0.402 \log CPI + 0.313 \log GDP2 - 0.169 \log WPI \\
&\quad + 0.337 \log EPI - 0.016 \log I + 0.017 \log OVI \\
&= 5.271 + (4.17) + (0.23) + (5.86)
\end{align*}
\]

\[
\begin{align*}
\nonumber R^2 &= 0.984 \\
\text{Adj}-R^2 &= 0.977 \\
S^2 &= 0.020 \\
\text{SSE} &= 0.282 \\
\text{Error DF} &= 14 \\
F\text{-value} &= 139.807
\end{align*}
\]

Definition of variables:

UCY: Urban household firewood demand in period \( t \).
CPI: Consumer price index.
GDP2: Wholesale price index of electricity.
WPI: Wholesale price index of wood and wood products.
EPI: Wholesale price index of electricity.
I: Growth in investment.
OVI: Import unit value index of oils and fats.
Table 5.15. Urban household aggregate woodfuel demand elasticities of unlagged model (t-ratios in parentheses)

<table>
<thead>
<tr>
<th>Equation</th>
<th>Coefficients</th>
<th>t-values</th>
<th>R^2</th>
<th>Adj-R^2</th>
<th>S^2</th>
<th>SSE</th>
<th>Error DF</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>log(UTY = 11.450 + 0.872 \log CPI)</td>
<td></td>
<td></td>
<td>0.867</td>
<td>0.860</td>
<td>0.120</td>
<td>2.283</td>
<td>19</td>
<td>124.197</td>
</tr>
<tr>
<td>(35.22) (11.14)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>log(UTY = 1.983 + 0.560 \log CPI + 0.457 \log GDP2)</td>
<td></td>
<td></td>
<td>0.963</td>
<td>0.960</td>
<td>0.035</td>
<td>0.632</td>
<td>18</td>
<td>236.069</td>
</tr>
<tr>
<td>(1.43) (9.02)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>log(UTY = 7.172 + 0.761 \log CPI + 0.305 \log GDP2 - 0.182 \log WPI)</td>
<td></td>
<td></td>
<td>0.982</td>
<td>0.979</td>
<td>0.018</td>
<td>0.306</td>
<td>17</td>
<td>313.315</td>
</tr>
<tr>
<td>(4.56) (11.74)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>log(UTY = 8.279 + 0.480 \log CPI + 0.321 \log GDP2 - 0.169 \log WPI)</td>
<td></td>
<td></td>
<td>0.983</td>
<td>0.979</td>
<td>0.018</td>
<td>0.288</td>
<td>15</td>
<td>234.724</td>
</tr>
<tr>
<td>+ 0.265 \log EPI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3.45) (1.63)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>log(UTY = 6.136 + 0.433 \log CPI + 0.321 \log GDP2 - 0.164 \log WPI)</td>
<td></td>
<td></td>
<td>0.984</td>
<td>0.978</td>
<td>0.019</td>
<td>0.284</td>
<td>15</td>
<td>178.557</td>
</tr>
<tr>
<td>+ 0.312 \log EPI - 0.016 \log I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3.24) (1.36)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5.15. Continued

\[
\log UTY = 6.247 + 0.410 \log CPI + 0.313 \log GDP2 - 0.169 \log WPI \\
(3.10) \quad (1.18) \quad (4.16) \quad (-3.23) \\
+ 0.330 \log EPI - 0.016 \log i + 0.017 \log OVI \\
(1.05) \quad (-0.45) \quad (0.22)
\]

\[R^2 = 0.984 \quad \text{SSE: 0.283} \]
\[\text{Adj-R}^2 = 0.977 \quad \text{Error DF: 14} \]
\[S = 0.020 \quad \text{F-value: 139.380} \]

Definition of variables:

UTY: Urban household aggregate woodfuel demand in period \( t \).

CPI: Consumer price index.

GDP2: Wholesale price index of electricity.

WPI: Wholesale price index of wood and wood products.

EPI: Wholesale price index of electricity.

I: Growth in investment.

OVI: Import unit value index of oils and fats.
Table 5.16. Urban household woodfuel demand elasticities of unlagged model: selected equations (t-ratios in parentheses)

<table>
<thead>
<tr>
<th></th>
<th>Firewood demand equation</th>
<th>Charcoal demand equation</th>
<th>Aggregate woodfuel demand equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>logUFY</td>
<td>( 4.572 + 0.762 \log \text{CPI} + 0.305 \log \text{GDP2} - 0.182 \log \text{WPI} ) (5.93)</td>
<td>( 6.212 + 0.761 \log \text{CPI} + 0.305 \log \text{GDP2} - 0.182 \log \text{WPI} ) (5.94)</td>
<td>( 7.172 + 0.761 \log \text{CPI} + 0.305 \log \text{GDP2} - 0.182 \log \text{WPI} ) (5.95)</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.982</td>
<td>0.982</td>
<td>0.982</td>
</tr>
<tr>
<td>Adj( R^2 )</td>
<td>0.979</td>
<td>0.979</td>
<td>0.979</td>
</tr>
<tr>
<td>S(^2)</td>
<td>0.018</td>
<td>0.018</td>
<td>0.018</td>
</tr>
<tr>
<td>( \text{SSE} )</td>
<td>0.306</td>
<td>0.306</td>
<td>0.306</td>
</tr>
<tr>
<td>( \text{Error DF} )</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>( \text{F-value} )</td>
<td>313.134</td>
<td>313.298</td>
<td>313.315</td>
</tr>
</tbody>
</table>

Definition of variables:

UFY: Urban household firewood demand in period t.
CPI: Consumer price index.
GDP2: Wholesale price index of electricity.
UCY: Urban household charcoal demand in period t.
UTY: Urban household aggregate woodfuel demand in period t.
woodfuel price (WPI). All variables are significant at better than the one percent level. Both the $R^2$ and the adjusted $-R^2$ are very high, indicating that the restricted model in equations (5.93) to (5.95) is very robust.

The parameter estimates in equations (5.93) to (5.95) also illustrate one of the important properties of least squares estimation, and that is, a linear transformation of the data does not alter the magnitude or size of the parameter estimates. As already indicated, the consumption of firewood by urban households is 94 kg/capita/year, while that of charcoal is 190 kg/capita/year. Thus, charcoal consumption is almost exactly two times that of firewood. In other words, charcoal (or firewood) consumption figures are a linear transformation of the firewood (or charcoal) consumption estimates, therefore, the parameter estimates of the two variables remain unchanged. This result can be seen in Table 5.16, and can also be contrasted to the parameter estimates on rural household woodfuel demand, Tables 5.1 to 5.8.

Thus, from Table 5.16, equations (5.93) and (5.95), the income elasticity of demand for firewood and charcoal by urban households is positive (0.305); indicating that in the short-run, a one percent increase in urban household income will result in a 0.31 percent increase in woodfuel consumption among urban households, all other things being equal. This positive income elasticity suggests that, in the short-run, woodfuel is a normal good. However, the model suggests that in the long-run, woodfuel demand is an inferior good. This can be seen from the negative correlation of woodfuel demand to the structural variable,
growth in investment (I) (Tables 5.9 to 5.11; Tables 5.13 to 5.15). The negative coefficients of the structural variable indicates that increasing structural change in the economy reduces woodfuel demand.

The own-price elasticity of demand for firewood and charcoal by urban households is negative (-0.18), indicating that, in the short-run, a one percent increase in woodfuel price reduces woodfuel consumption among urban households by 0.18 percent, all other things being equal. This negative own-price elasticity again suggests that, in the short-run, woodfuel is a normal good.

From the results of the restricted model, equations (5.93) to (5.95), the problem of model identification may arise in this case since woodfuel demand is a function of price. A model is said to be identified "... if it is in a unique statistical form, enabling unique estimates of its parameters to be subsequently made from sample data" (Koutsoyiannis, 1977). But this may not be easy to accomplish in supply and demand analysis because both supply and demand are functions of price. Koutsoyiannis (1977, p. 95) succinctly states this problem as follows:

Market data registers points of equilibrium of supply and demand at the price prevailing in the market at a certain point of time. A sample of time-series observations show simultaneously the quantity demanded, D, and the quantity supplied, S, at the prevailing market price, P. If we use these data for estimation, we actually measure the coefficients of a function of the form Q = F(P). This equation may be either the demand function or the supply function. ... How can we be sure which function we do really measure?

In other words, in supply and demand analysis the identification problem arises because quantity bought is identical with quantity sold at
a particular time, and therefore a researcher may not be sure whether it is supply or demand being estimated.

However, there are formal rules which enable a researcher to verify that the estimated coefficients belong to one function or another (Koutsoyiannis, 1977; Maddala, 1988). One such rule is to impose restrictions on the values of the parameters of some variables when either supply or demand is being measured. For instance, to identify the demand function for woodfuel, restrictions are imposed on the parameters of the supply function; more specifically, the parameters of the supply function are restricted to be zero. This is because imposing zero restrictions on the values of parameters in the woodfuel demand function means that the variables to which the parameters refer do not appear in the woodfuel demand function. Therefore, to measure the woodfuel demand function, supply shift factors such as weather and stocks are excluded as regressors in the demand function.

The zero restrictions are made on the basis of prior knowledge about supply shift factors. Thus, one observation often made is that supply responds to price changes with a lag, that is $S = f(P_{t-1})$ (Koutsoyiannis, 1977). In other words, demand adjusts to current price shocks while supply does not.

However, in the case of woodfuel supply in Zambia, charcoal supply has been observed to be very seasonal, being lower during the rainy season from November to April (Chidumayo, 1990a; World Bank, 1988, 1990). There are two main reasons for this. First, most charcoal is prepared in traditional earth or pit kilns, and these cannot be employed during the
rainy season. Second, access to wooded areas is very difficult during
the rainy season because of dambos. Chidumayo (1990a, p. 30) has
stated:

Dambos are grasslands and, therefore, contain little woody
biomass. However, the wooded plateau interfluves are inter­
spersed by wide dambos. These dambos become waterlogged during
the rainy season and, therefore, almost impassable to motor
vehicles. This creates difficulties in biomass collection and
transportation during the rainy season. Streams and rivers
without bridges present similar limitations on access to
biomass areas. In Zambia, feeder tracks to woodfuel areas are
merely wheel-ruts in the bush created by repeated use by motor
vehicles. Often these tracks also become muddy, waterlogged
and dangerous to drive on. Thus, there is a severe seasonal
constraint on access to biomass areas in the rainy season due
to transportation difficulties.

It is, therefore, the case that woodfuel supply is severely con­
strained by weather, transportation and technology. On the other hand,
these supply shift factors have an indirect or spurious effect on
woodfuel demand, through charcoal prices. In other words, seasonality in
woodfuel supply introduces seasonality in woodfuel prices, the prices
being higher during the rainy season. For instance, during the 1988-89
rainy season, the price of charcoal in Lusaka was observed to rise from
K30/40 kg bag before the start of the rainy season to K150/40 kg bag
during December-February; and to fall to a low of K70/40 kg bag after the
rainy season (World Bank, 1990). It is these factors which assist in
identifying the woodfuel demand function.

Meanwhile, the cross-price elasticities of electricity and oil­
based fuels suggest that these energy sources are substitutes for
woodfuel (Tables 5.13 to 5.15). The coefficients are positive though
insignificant, suggesting some degree of interfuel substitution, especially given the seasonality in woodfuel supply.

It is also noteworthy that inflation is the most significant determinant of urban household demand for woodfuel, just as the case of rural households. From Table 5.16 equations (5.93) and (5.94) the inflation elasticity of demand for firewood and charcoal by urban households is positive (0.762); indicating that, in the short-run, a one percent increase in inflation will result in a 0.76 percent increase in woodfuel demand by urban households, all other things being constant. Clearly then, inflation has a pervasive effect on both rural and urban household demand for woodfuel.

The overriding effect of inflation on woodfuel demand seems to contradict the basic property of demand functions depicted in equation (4.15), that household consumption decisions are made in response to changes in relative and not general price levels. By definition, inflation is a sustained increase in the general price level, or as Gordon (1978, p. 187) puts it: "inflation is an upward movement in prices that is: (1) shared by all components of the price deflators and (2) sustained." On the other hand, the homogeneous property of demand functions in equation (4.15) shows that if all prices change in the same proportion, the quantities demanded remain unchanged, therefore, by this property of demand functions, inflation may not be expected to have such an overriding effect on woodfuel demand in Zambia.

However, there are two main reasons inflation could be expected to have such a significant effect on woodfuel demand. First, the proxy used
for inflation, the consumer price index, is better than the wholesale price index in reflecting consumer behavior. This is because the consumer prices include taxes while wholesale prices do not. It is, therefore, the case that the consumer price index will provide a better regression fit than wholesale price indices such as those of electricity and the proxy for woodfuel price. Second, inflation does not raise the prices of all commodities by the same proportion. As a result, even with the general price increase during an inflationary period, some commodities become cheaper relative to others, and this violates the homogeneous property of equation (4.15).

There is now a general consensus that the adverse effects of inflation on household consumption arise from two factors (Gordon, 1978; Sargent, 1979). First, inflation cannot accurately be anticipated. It is very difficult to forecast exactly when and how inflation will occur and, therefore, it is very difficult for consumers to protect themselves against inflation. Second, inflation does not raise the prices of all commodities by the same percentage rate, and therefore relative prices change during an inflationary period.

The combined effect of these two factors results in gainers and losers from inflation. The gainers are debtors, business firms and the government while the losers are retirees and those people on fixed incomes, as well as very poor people since they lack the finances and access to bonds.
However, even if inflation is fully anticipated and raises all prices by the same percentage rate, consumers would still incur what are known as shoe-leather costs (Gordon, 1978). The view is that accurately anticipated inflation has no effect on consumption, saving and investment decisions; but because of inflation, people make extra efforts to manage their finances. As a result, "they use up 'shoe leather' taking extra trips to the bank, and the welfare cost of anticipated inflation is sometimes called the shoe-leather cost" (Gordon, 1978, p. 292).

Besides, the situation depicted in Table (4.2) and Appendix B for the case of Zambia is worse than inflation; it is a simultaneous occurrence of inflation and recession. This situation is often called stagflation, an inflationary recession which Gordon (1978, p. 35) defines as: "a situation which combines stagnation (zero or negative output growth) with inflation." As indicated earlier, the high levels of inflation in Zambia can be seen from the precipitous drop in the foreign exchange rate of the Zambian Kwacha; a fall of 93% in value during the period 1975-1987. Meanwhile, the conventional measure of inflation, the consumer price index (CPI) has been rising steadily since 1973, but more so during the past decade. As a result of these factors, consumer purchasing power has fallen sharply. For instance, in 1987, 2.17 Kwacha were required to purchase the same bundle of goods that only one Kwacha did in 1985, and only 20 ngwee or 0.20 Kwacha did in 1975 (Table 4.2).

Similarly, during the past decade, there has been recurrent negative growth in real GDP and persistent fall in per capita income (Appendices B and C). The per capita income in Zambia has fallen from a high K758 in
1969 to K474 per annum in 1984; a fall of 63% during the period 1969-1984.

It is the combined effect of all these factors which explains why inflation is such a significant determinant of woodfuel demand in Zambia. On the one hand, the higher inflationary prices and reduced purchasing power increase woodfuel demand as consumers spend more rapidly. On the other hand, the negative real growth in GDP, and fall in per capita income increase the dependency on woodfuel because it is cheaper to cook with woodfuel than with conventional sources of energy such as electricity and kerosene (see also Chapter VI below).
CHAPTER VI. SUPPLY OF WOOD AS A SOURCE OF ENERGY

The Theory of Exhaustible Resources

The principal hypothesis concerning the supply of wood as a source of energy in Zambia is that large quantities of woodfuel cannot be supplied through natural tree growth and regeneration; therefore, it is necessary to implement a program of woodfuel production from tree plantations and agroforestry systems. This hypothesis is abstracted from the recurrent view that forests in developing countries are an exhaustible resource. The usual definition of an exhaustible resource is that it is a resource which is fixed in supply and is nonrenewable (Conrad and Clark, 1987). This definition includes as exhaustible resources oil, copper, coal and other minerals; and excludes forests, fisheries and surface water. However, there is a recurrent view that forests in developing countries are an exhaustible resource. For instance, David French (1985) argues that deforestation is irreversible in most developing countries unless there is a drastic increase in family incomes to enable a large segment of the population to substitute from woodfuel to commercial fuels. According to French, the only solution to continued deforestation is a drastic increase in family incomes; but, he argues, this is not possible given the recent negative growth in incomes in most developing countries, hence the conclusion that deforestation is irreversible. Based on his experience in Malawi, French (1985, p. 161) identifies other factors to support his conclusion that deforestation is irreversible, and he states these factors as follows:
In developing countries, indigenous woodlands are a non-renewable resource, like petroleum. This means two things. First, once indigenous woodlands are cut down, they are gone forever. Usually, the land will be taken over for agriculture or expansion of urban areas. Where there is re-forestation, this will be through fast-growing species, not re-establishment of indigenous trees. In many developing countries, indigenous woodlands will disappear permanently long before the petroleum does.

Second, like oil in the ground, standing indigenous trees have been considered to be "free." In addition, the extraction preparation and transportation of indigenous wood has been at very low cost. Moreover, enduse technologies have often cost nothing: take, for example, the three stones that comprise the basic stove for cooking with wood. All things considered, indigenous woodlands have been the closest that humanity will ever come to having a free source of energy.

Similar observations are also made by the Economic Commission for Africa (ECA), of the United Nations, in its study of the Miombo forests of eastern Africa (FAO, 1986b). The "Miombo" forests are open tropical forests comprised mainly of the species Brachystegia and Julbernardia in eastern Africa, they cover the largest area of natural forest land. The ECA study is on Mozambique, Tanzania and Zambia; however, the study (FAO, 1986b, p. 24) makes the following observations about eastern Africa as a whole:

A form of miombo forest management carried out in most of these countries is selective harvesting. This system promotes the exploitation of valuable species, leaving the undesirable and crooked trees in the forest. This form of exploitation has made natural regeneration very difficult and in certain areas there are no seed trees whatsoever to favor regeneration of these species. Obviously, this practice leads to irreversible degradation of the miombo, especially considering their low stocking per hectare (estimated as 34 m$^3$ per hectare for the sub-region as a whole). Moreover, if to this lack of silvicultural treatment are added the effects of over-exploitation (where in many cases the volume actually commercialized exceeds
three times the annual allowable cut (AAC)) it is easy to understand why these forests have failed to attract investment in the sub-region.

The main techniques used for encouraging regenerating are root suckers, seedlings and the coppice system. There have also been attempts to enrich degraded forests with faster growing indigenous or even exotic tree species. In the Ndola area of Zambia, it has been reported that root suckers are encouraged by human activities such as agriculture and charcoal burning. In short, at present there is very little silviculturally-induced regeneration. Nature is left to take care of itself.

Furthermore, some authors suggest that management of tropical forests is very difficult. In particular, Morgan and Moss (1981) point to the problem of trying to manage the ecological interactions in tropical forests. As noted earlier in Chapter II, a theme which runs through much of the study by Morgan and Moss is that in tropical areas, natural forests provide good timber, but are an inefficient source of woodfuel. Morgan and Moss suggest that reliance on natural regeneration and self-propagated forests is not a viable option for the provision of woodfuel in most areas of tropical Africa and Asia. This, the authors argue, "... results from the complexity of the ecological interactions involved, from our ignorance of these interactions, and from the considerable problem of maintaining these interactions even if they were satisfactorily understood" (Morgan and Moss, 1981).

The origin of the economics of exhaustible resources is itself traced to the work of Gray (1914) while the foundation of the theory of exhaustible resources is attributed to the work of Hotelling (1931). Thus, according to Hotelling, forests are an exhaustible resource, and he explains this as follows: "The forests of a continent occupied by a new
population may, for purposes of a first approximation at least, be regarded as composed of two parts, of which one will be replaced after cutting and the other will be consumed without replacement. The first part obeys the laws of static theory; the second, those of the economics of exhaustible assets" (Hotelling, 1931, p. 140). In other words, some forests are exhaustible while others are not, and Duerr (1960) observes that forest stocks that are not growing are exhaustible. According to Duerr (1960, p. 138), although forests are renewable, the theory of exhaustible resources applies to forests in at least two cases:

The first is the case of virgin timber, which clearly is exhaustible, and to a degree also the case of soils and some other assets of the forest watershed. The second is the case of any of the forest resources, including growing timber and wildlife, which an owner believes is exhaustible. For remember that a person's rational behavior is based upon what he thinks, and not necessarily upon what is the fact. If I have a sack of diamonds and believe it is a sack of garbage, I will surely toss it out for the garbage collector.

Gray, Hotelling, Duerr and other economists have established what is often called the fundamental principle of the economics of exhaustible resources. This principle may be illustrated as follows. Let:

\[ P_t \] = market price of a resource in period \( t \).

\[ C \] = marginal extraction cost, assumed to be constant.

\[ R_t = P_t - C; \] net price in period \( t \).

\[ R_{t+1} = P_{t+1} - C; \] net price in period \( t+1 \).

\[ \Delta R_t = R_{t+1} - R_t; \] change in net price.

\[ r = \text{interest rate.} \] (6.1)
Then the fundamental principle may be stated in the following cases.

\[
\text{Case 1: } \frac{\Delta R_t}{R_t} < r \quad (6.2)
\]

In this case, the market price minus extraction cost, i.e., the net price, rises at a rate lower than the interest rate. This condition induces a profit-maximizing firm or individual supplier to extract and sell the whole stock of the resource as soon as possible in order to invest the proceeds in alternative ventures which yield the market rate of interest. Clearly, this condition accelerates the depletion of resources, it is the reason conservationists argue against high interest rates (Duerr, 1960; Gordon, 1967).

\[
\text{Case 2: } \frac{\Delta R_t}{R_t} > r \quad (6.3)
\]

In this case, the market price minus extraction cost rises at a faster rate than the interest. This condition induces a profit-maximizing firm to leave the resource in the ground because extracting the resource lowers the firm's net present value.

\[
\text{Case 3: } \frac{\Delta R_t}{R_t} = r \quad (6.4)
\]

In this case, the net price rises at the rate of interest, and is such that there is output supplied in every period. This is an equilibrium condition and is what is required by the fundamental principle. In other words, the fundamental principle of the economics of exhaustible resources holds that: "the market price of the resource net of extraction costs must rise at a rate equal to the rate of interest" (Webb and
Ricketts, 1980, p. 38). Any situation outside this, i.e., cases 1 and 2, either accelerate or decelerate the depletion of resources.

In his seminal work, Hotelling (1931) argues against free competition and in favor of monopoly in the exploitation of exhaustible resources because monopoly decelerates the exhaustion of resources by restricting output and charging a higher price than would prevail under competition. The assumption is that the objective function of a firm supplying an exhaustible resource is to maximize the net present value of the firm's future profits subject to the fixed supply of the resource. That is:

\[
\text{maximize} \quad \text{NPV} = \pi_t (1+r)^{-t}
\]

subject to \( \sum_{t=0}^{T} q_t = q \) \hspace{1cm} (6.5)

where NPV is net present value, \( \pi_t \) is profit in period \( t \), \( r \) is interest rate, \( (1+r)^{-t} \) is the discount factor, \( q_t \) is output in period \( t \), and \( T \) is the time of exhaustion of the resource. Then the profit function of a competitive firm is:

\[
\pi_t = p_t q_t - C q_t \quad (6.6)
\]

where \( p_t q_t \) are the total revenues of the firm in period \( t \), \( C q_t \) are the total costs of the firm in period \( t \), and where \( \pi_t \) and \( C \) are defined as before. Then, the discounted future profits are:

\[
\text{NPV} = \pi_t (1+r)^{-t} = (p_t q_t - C q_t) (1+r)^{-t} \quad (6.7)
\]

where all the terms are defined as before. The objective of the firm is to maximize the sum of discounted profits subject to the constraint (6.5); that is:
maximize \[ \sum_{t=0}^{T} \pi_t (1 + r)^{-t} = \sum_{t=0}^{T} (p_t q_t - c q_t) (1 + r)^{-t} \]

subject to \( \sum_{t=0}^{T} q_t = \bar{q} \) (6.8)

The Lagrangean function for this problem is:

\[ L = \sum_{t=0}^{T} (p_t q_t - c q_t) (1 + r)^{-t} - \lambda (\sum_{t=0}^{T} q_t - \bar{q}) \] (6.9)

The first-order conditions for a maximum are:

\[ \frac{\partial L}{\partial q_t} = (p_t - c)(1 + r)^{-t} - \lambda = 0 \quad (t=0, 1, \ldots, T) \]

\[ \frac{\partial L}{\partial \lambda} = \sum q_t - \bar{q} = 0 \] (6.10)

Solving (6.9) for \( p_t \) yields:

\[ p_t = c + \lambda (1 + r)^{t} \] (6.11)

Equation (6.11) shows that price in period \( t \) equals marginal extraction cost plus the term \( \lambda (1 + r)^{t} \). This term, \( \lambda (1 + r)^{t} \), has been called "user cost" because "...it arises from the fact that using the resource in the present eliminates the possibility of its use in the future" (Webb and Ricketts, 1980, p. 39). Thus, equation (6.11) shows that price in period \( t \) equals marginal extraction costs plus user cost. Then, defining \( R_t \) and \( R_{t+1} \) as before, and from equation (6.11)

\[ R_t = p_t - c \]

\[ p_t = c + \lambda (1 + r)^{t} \] (6.12)

Therefore,

\[ R_t = \lambda (1 + r)^{t} \]

\[ R_{t+1} = \lambda (1 + r)^{t+1} \] (6.13)
Subtracting $R_{t}$ from both sides of $R_{t+1}$ in (6.13) yields:

$$R_{t+1} - R_{t} = \lambda(1 + r)^{t+1} - \lambda(1 + r)^{t} = \lambda(1 + r)^{t+1} - \lambda(1 + r)^{t}$$  (6.14)

Dividing (6.14) by $R_{t}$ and simplifying yields:

$$\frac{R_{t+1} - R_{t}}{R_{t}} = \frac{\lambda(1 + r)^{t+1} - \lambda(1 + r)^{t}}{\lambda(1 + r)^{t}}$$

or

$$\frac{\Delta R_{t}}{R_{t}} = r$$  (6.15)

This is the fundamental principle of the economics of exhaustible resources as depicted earlier in equation (6.4).

On the other hand, the profit function of the monopoly is:

$$\pi_{t} = p_{t}(q_{t})q_{t} - c_{t}q_{t}$$  (6.16)

where all the terms are defined as before. Thus, the major difference between the profit function of the monopoly (6.16) and that of the competitive firm (6.6) is that monopoly price is a function of output. This difference arises from the fact that a monopoly is a price-setter while a competitive firm is a price-taker, and the price that a monopoly sets depends on the output sold. However, the objective functions of both firms are identical: to maximize the sum of discounted profits subject to the constraint (6.5). That is, for the monopoly, the objective function is to:

$$\text{maximize } \sum_{t=0}^{T} \pi_{t}(1 + r)^{-t} = \sum_{t=0}^{T} (p_{t}(q_{t})q_{t} - c_{t})(1 + r)^{-t}$$

subject to $\sum_{t=0}^{T} q_{t} = \bar{q}$  (6.17)
The Lagrangean function for this problem is:

\[ L = \sum_{t=0}^{T} (p_t q_t - C q_t)(1 + r)^{-t} - \lambda \left( \sum_{t=0}^{T} q_t - q \right) \]  

(6.18)

The first-order condition for a maximum is:

\[ \frac{\partial L}{\partial q_t} = (p_t - q_t - C)(1 + r)^{-t} - \lambda = 0 \quad (t=0, 1, \ldots, T) \]

(6.19)

Solving (6.18) for \( p_t \) yields:

\[ p_t = C + q_t \frac{\partial p_t}{\partial q_t} + \lambda (1 + r)^t \]  

(6.20)

By the law of demand \( \frac{\partial p_t}{\partial q_t} \) is negative. Therefore, monopoly price (6.20) is greater than competitive price (6.11) by the term \( q_t \frac{\partial p_t}{\partial q_t} \).

Thus, under monopoly, the fundamental principle of exhaustible resources amounts to:

\[ \frac{\Delta R^*}{R^*_t} = r \]  

(6.21)

where \( R^*_t = p_t + q_t \frac{\partial p_t}{\partial q_t} - C \).

This is the basis for Hotelling's argument that monopoly restricts output, charges a higher price than a competitive firm, and, therefore, slows down the rate of resource depletion.

Clearly, Hotelling's observations have significant implications for natural resource policy. There are several reasons which can be advanced against a policy of laissez-faire in the allocation of natural resources.
One is the fact that the objective of a competitive firm may not be the same as the objective of society. Another reason is the fact that when conditions of free competition exist in practice, they are likely to be far from ideal.

The fundamental principle is assumed to operate under a set of conditions. These conditions are that: (a) the future is certain, (2) the size of the resource stock is known, (3) the content of the resource stock is homogeneous, (4) the shape of the demand curve is known, (5) there are well-functioning futures markets, and (6) there are clearly defined property markets (Webb and Ricketts, 1980). These conditions are difficult to realize in practice. In particular, a basic problem found in most developing countries is resource mismanagement due to common property rights (Livingstone, 1986; Runge, 1986; Picardi and Seifert, 1976). The problem is that in most developing countries, natural resources are exploited as a "free" good on common land and on government land, and this makes it difficult for autonomous adjustments in the demand and supply of the resources.

The general consensus is that a common-property resource is over-exploited (Dasgupta and Heal, 1979; Conrad and Clark, 1987). The basic problem is often referred to as the "tragedy of the common" that a common property resource gets used by everybody until it is of no use to anybody. The "tragedy of the common" arises because of two conditions which characterize the common property resource. These conditions are: (1) unrestricted access to the resource by all those who care to use the resource, and (2) some type of adverse interaction among users of the
resource; i.e., creation of "externality" among the users. Given that there is unrestricted access to the resource and given competitive conditions under common property, it is not in the interest of a single firm or user to conserve the resource because the output will be lost to another user. The result is over-exploitation and accelerated depletion of the resource.

These then, are some of the reasons which discourage a policy of unregulated competitive extraction of exhaustible resources. However, this is not to suggest that monopoly is appropriate for conservation of the resources. Compared to a competitive firm, a monopoly is generally considered to be inefficient because it does not minimize average costs. In the long-run, a competitive firm operates with an optimal plant size such that average costs are minimized (Miller, 1978; Nicholson, 1983). A monopoly, on the other hand, has less incentive to minimize average costs and produce efficiently, and these may be reflected in high prices to consumers. Therefore, other instruments of policy should be considered. For instance, in equations (6.4) and (6.15), a fall in interest rate, all else being equal, lowers the net price and, therefore, slows down the rate of resource depletion. Similarly, an increase in extraction costs, all else being equal, lowers the net price, and decelerates resource depletion.

There are other possibilities such as substitution in the end-use of the resource, and additions to resource stocks through production and new discoveries of reserves. Additions to tree stocks, for instance, can be realized through natural regeneration by coppice; from the stand point of
society, the rules for optimal management of an exhaustible but renewable resource can be derived as follows (Webb and Rickets, 1980; Conrad and Clark, 1987). Each individual in society has a utility function:

$$U_i = U_i(C_i)$$  \hspace{1cm} (6.22)

where $U_i$ is the utility function of individual $i$, and $C_i$ is the consumption of individual $i$. By assumption:

$$U_i'(C_i) > 0$$  \hspace{1cm} (6.23)

$$U_i''(C_i) < 0$$

These assumptions characterize the function $U_i(C_i)$, and indicate that an addition to an individual's consumption always increases the individual's utility but at a diminishing rate. They are the usual assertions made about the utility function. Three additional assumptions are made in order to derive a social welfare function (SWF). These are that: (1) all individuals in society have identical or homothetic preferences, (2) total social welfare ($W$) in any period is the sum of total individual utilities,

$$W_t = \sum_{t=0}^{\infty} U(C_t)$$  \hspace{1cm} (6.24)

and (3) total social welfare over time ($W^*$) is the discounted sum total of social welfare at each time,

$$W^* = \sum_{t=0}^{\infty} U(C_t)(1+r)^{-t}$$  \hspace{1cm} (6.25)

Then two cases are considered in order to obtain the optimal consumption paths of society over time. The first case is the case of an exhaustible
and nonrenewable resource. This is sometimes referred to as the "cake eating" model (Webb and Ricketts, 1980). In this case, there is a fixed stock of a consumption good \( q \), and the good is nonrenewable. That is:

\[
\sum_{t=0}^{T} q_t - \bar{q} = 0 \quad (6.26)
\]

Assuming, for simplicity, there are no extraction costs, the optimization problem of society is to consume the stock in such a way as to maximize the discounted total welfare (6.25) subject to the fixed stock of the resource (6.26). That is:

\[
\text{maximize } W^* = \sum_{t=0}^{T} U(C_t)(1+r)^{-t}
\]

\[
\text{subject to } \sum_{t=0}^{T} q_t = \bar{q} \quad (6.27)
\]

The Lagrangean function is:

\[
L = \sum_{t=0}^{T} U(C_t)(1+r)^{-t} + \lambda(\bar{q} - \sum_{t=0}^{T} q_t) \quad (6.28)
\]

The first-order conditions for a maximum are:

\[
\frac{\partial L}{\partial q_t} = U'(C_t)(1+r)^{-t} - \lambda = 0 \quad (0, 1, \ldots, T)
\]

\[
\frac{\partial L}{\partial \lambda} = \bar{q} - \sum_{t=0}^{T} q_t = 0 \quad (6.29)
\]

From (6.29),

\[
U'(C_t) = \lambda(1+r)^t \quad (6.30)
\]

where \( U'(C_t) \) is the marginal utility of consumption. Thus, as the proportionate change in \( U'(C_t) \) can be seen to be related to \( r \), the discount rate. That is:
Equation (6.31) indicates that the marginal utility of consumption \( U'(C_t) \) should optimally increase at a rate equal to the discount rate, \( r \). Since the period of time \( T \) is fixed, then the allocation problem is one of choosing \( r \). Suppose, for instance, \( r = 0 \), in other words, suppose future utilities are not discounted, then from (6.30):

\[
U'(C_t) = \lambda
\]

(6.32)

This is the case of zero pure time-preference, and one in which the marginal utility of consumption is constant over time, and therefore, consumption is constant over time. Suppose \( r \) is positive, then from (6.30):

\[
U'(C_t) = \lambda(1+r)^t > 0
\]

(6.33)

This is the case of a positive pure time-preference, and one in which the marginal utility of consumption is rising but consumption of \( q_t \) is declining over time, by assumption (6.23). Thus, given a fixed quantity of the resource \( q_t \), and positive but declining consumption of \( t \), the social problem is deciding on the time \( T \) when the resource should be depleted. "Clearly in these circumstances the stock cannot be made to last indefinitely, and the inter-temporal allocation problem involves fixing a date for the end of the world. As one would expect, the existence of pure time-preference advances this fateful day while a zero pure
time-preference rate recommends a policy of equal consumption per period" (Webb and Ricketts, 1980, p. 53).

This "cake-eating" model has the major deficiency of not accounting for production. The fact is, there are exhaustible but renewable resources. This is the second case to be considered; of exhaustible but renewable resources such as forests. The production function in this case is assumed to be:

\[ Q_t = F(K_t, q_t) \]  \hspace{1cm} (6.34)

where \( Q_t \) is the production function, \( K_t \) are capital inputs in period \( t \). Output of an exhaustible resource, \( Q_t \), is assumed to be in the form of a good which can either be consumed directly or be used as capital in the production of itself. Examples are a corn crop in agriculture and a seed tree in forestry. Corn may be consumed now or used as capital input in the production of next year's harvest. Similarly, a seed tree may be used now or used as capital input in the production of future trees. Thus, output may be used either for consumption or for adding to capital:

\[ Q_t = C_t + \Delta K_t \]  \hspace{1cm} (6.35)

where \( \Delta K_t = K_{t+1} - K_t \). Substituting (6.35) into (6.34) yields:

\[ F(K_t, q_t) = C_t + \Delta K_t \]  \hspace{1cm} or \hspace{1cm} \[ F(K_t, q_t) = C_t + \Delta K_{t+1} - K_t \]  \hspace{1cm} (6.36)

The society's problem then is to maximize discounted social welfare (6.25) subject to the constraints (6.26) and (6.36). That is:

\[ \text{maximize } W^* = \sum_{t=0}^{\infty} U(C_t)(1+r)^{-t} \]
subject to $\sum_{t=0}^{T} q_t = \bar{q}$

and $F(K_t, q_t) = C_t + \Delta K_{t+1} - K_t$ (6.37)

The Lagrangean function is:

$$L = \sum_{t=0}^{T} U(C_t)(1+r)^{-t} + \lambda \left( \bar{q} - \sum_{t=0}^{T} q_t \right) + \lambda_t [F(K_t, q_t) - C_t + \Delta K_t]$$ (6.38)

The first-order conditions for a maximum are:

$$\frac{\partial L}{\partial C_t} = U'(C_t)(1+r)^{-t} - \lambda_t = 0$$

$$\frac{\partial L}{\partial q_t} = \lambda_t F_{q_t} - \lambda = 0$$

$$\frac{\partial L}{\partial K_t} = \lambda_t F_{K_t} - \lambda_{t+1} - \lambda_t = 0$$

$$\frac{\partial L}{\partial \lambda} = q - \sum_{t=0}^{T} q_t = 0$$

$$\frac{\partial L}{\partial \lambda_t} = F(K_t, q_t) - C_t + \Delta K_{t+1} - K_t$$ (6.39)

where $F_{q_t}$ and $F_{K_t}$ are the partial derivatives of the function $F$ with respect to $q_t$ and $K_t$. Assuming that second-order conditions for a maximum are satisfied, the optimal consumption path is obtained as follows. From the partial derivative with respect to $C_t$:

$$\lambda_t = U'(C_t)(1+r)^{-t}$$

or

$$\lambda_t = \frac{U'(C_t)}{(1+r)^t}$$ (6.40)
From the partial derivative with respect to $K_t$:

$$-\lambda_t F_{kt} = \lambda_t - \lambda_{t-1}$$  \hspace{1cm} (6.41)

Dividing (6.41) by $\lambda_t$ yields:

$$-F_{kt} = \frac{\lambda_t - \lambda_{t-1}}{\lambda_t}$$  \hspace{1cm} (6.42)

Substituting (6.40) into (6.42) yields:

$$\frac{U'(C_t)}{U'(C_{t-1})} \frac{U'(C_{t-1})}{U'(C_t)} \frac{(1+r)^t}{(1+r)^{t-1}} \frac{U'(C_t)}{(1+r)^t} = -F_{kt}$$

Transposing yields:

$$U'(C_t) = U'(C_{t-1})u(1+r) - F_{kt}U'(C_t)$$

Dividing through by $U'(C_{t-1})$ and subtracting -1 from both sides yields:

$$\frac{U'(C_t) - U'(C_{t-1})}{U'(C_{t-1})} - r = F_{kt} \left[ \frac{U'(C_t)}{U'(C_{t-1})} \right]$$

or

$$\frac{\Delta U'(C_{t-1})}{U'(C_{t-1})} - r = F_{kt} \left[ \frac{U'(C_t)}{U'(C_{t-1})} \right]$$  \hspace{1cm} (6.43)
In terms of continuous time, equation (6.43) reduces to:

\[
\frac{d}{dt} \frac{U'(C)}{U(C)} = r - F_k
\]  

(6.44)

Equation (6.44) indicates that if the marginal product of capital, \( F_k' \), exceeds the rate of interest, \( r \), that is, if \( F_k' > r \), the change in the marginal utility of consumption, \( [dU'(C)/dt]/U'(C) \), is negative, therefore, by the assumptions of (6.23), consumption is rising. The opposite is equally true. Thus, for instance, a rise in the consumption of woodfuel over time requires continuous production of biomass, and in that case, the marginal product of capital employed in production should be greater than the rate of interest.

Equation (6.44) also illustrates the optimal management of a growing forest resource. The optimum occurs when the marginal product of capital employed in the production of the forest resource is equal to the interest rate, that is:

\[
F_k = r
\]  

(6.45)

where \( F_k \) and \( r \) are respectively the marginal product of capital and the interest rate. When this condition holds, the marginal utility of consumption in equation (6.44) is zero, indicating that consumption is at its peak.

Similarly, another model of the optimal management of a growing forest stock is that of financial maturity, a concept suggested by Duerr (1960). According to this model, financial maturity of a growing forest stock occurs when the marginal value growth of the forest stock is equal to the interest rate, that is:
where $mv$ is marginal value and $r$ is the firm's interest rate. Marginal value is also marginal revenue and is derived from stumpage sales less variable costs.

Duerr distinguishes between variable costs for a stand and a tree, and, therefore, distinguishes between financial maturity for a stand and a tree. For the stand, variable costs are of three types: "(a) the cost of waiting out the rotation, (b) the cost of postponing the yields from subsequent rotations (reduced by the gain from postponing management outlays, if any, in subsequent rotations), and (c) the cost of regulating the timber growing stock in such fashion that yields can be harvested annually" (Duerr, 1960, p. 131). For the individual tree, variable costs are of two types: those described in categories (b) and (c) above. In other words, calculation of financial maturity for the individual tree does not account for the cost of waiting, "Since a tree, unlike a stand, must usually be harvested entirely or not at all . . . ." (Duerr, 1960, p. 132). The difference then in financial maturity between a stand and a tree is in the definition of marginal value growth, otherwise the concept of financial maturity is useful in determining when to harvest a stand or a tree. As Duerr (1960, p. 131) suggests:

The financial-maturity concept with necessary adjustments incorporated on the basis of good sense is usable in the woods for setting rotation age of a stand. It is a useful tool also in another, and more common, timber-management job, that of deciding when to mark an individual tree for cutting--under any system of management.
The point is that wood is a renewable resource but society can choose not to renew it. When the decision is to renew the wood resource, it can be managed on a sustained basis through, for instance, consumer utility maximization or financial maturity as determined by the firm.

Supply of Wood as a Source of Energy in Zambia

Zambia has a tropical climate with 16 types of forest and woodland (Table 6.1). However, only seven types of vegetation are the most dominant in terms of total area (Table 6.2). As noted earlier, miombo woodland is the most common type of vegetation, representing 58% of the total wooded area or 47% of the total land area in Zambia.

Overall, forest and woodland are estimated to cover 50 million hectares or 66% of the 75.3 million hectares of total land area in Zambia (Table 6.5), indicating that a large segment of the total land area in Zambia is still covered by forest and woodland. However, deforestation is still a major issue in Zambia for several reasons. One reason is that there is an imbalance in the spatial distribution of the country’s population and vegetation cover: densely populated areas have fewer forests and woodlands (Table 6.3). The opposite is equally true. In other words, there is a negative correlation between the spatial distribution of the population and vegetation cover. Thus, some areas face significant wood supply deficits and external costs of deforestation (FAO, 1986a; World Bank, 1990). This is the situation in the provinces in which the largest urban areas are located.
Zambia is divided into nine provinces and the largest urban areas are found in the Copperbelt, Lusaka and Southern provinces (Table 6.3). These provinces account, respectively, for 23%, 14%, and 12% of the Zambian population, but have the least forest and woodland cover of 6%, 2% and 7% of the total forested areas in Zambia, respectively. On the other hand, the Western, Luapula, and North Western Provinces account, respectively, for 8%, 7% and 5% of the Zambian population but have the most forest and woodland cover of 22%, 12% and 25% of the total forested area in Zambia, respectively. It is this negative correlation of the spatial distribution of population to vegetation cover which has led to significant wood supply deficits and deforestation in the Copperbelt, Lusaka and Southern Provinces.

However, deforestation is also an important issue in the sparsely populated but significantly forested provinces. The problem in this case is that of shifting cultivation or the "chitemene" system, as it is often called. Shifting cultivation is practiced mainly in the Northern and Luapula Provinces and to a lesser degree in other provinces in Zambia. The system involves cutting down bush, lopping tree branches and heaping these into circles. This is done during the dry season. At the beginning of the rainy season, the heaped biomass is burnt, and then crops are planted. The ash is intended to provide soil nutrients for at least one growing season before the farmer shifts to another patch of wooded area to repeat the circle of deforestation. It is estimated that 40,000 hectares are each year deforested by this system of cultivation in Zambia (FAO, 1986b).
It is sometimes suggested that the solution to shifting cultivation is settled agriculture. This is one of the principal recommendations the United Nations Economic Commission for Africa, ECA, makes to Mozambique, Tanzania and Zambia in its report on policies and strategies for the development of miombo forests in eastern Africa. The ECA proposes: "the launching of a progressive and general plan to change the present systems of shifting cultivation, into a permanent sustained agriculture, under woodland cover. This plan, based, mainly on cash crop cultivation should include agro-silviculture and livestock approaches and would require the financial and political governmental support of these countries" (FAO, 1986b, p. 7). This seems a plausible solution, especially that in Zambia, the region where shifting agriculture is practiced has the highest average annual rainfall in the country. However, shifting agriculture is practiced because the region is ill-suited for settled agriculture. Shifting agriculture is practiced because the soil is poor and acidic. As the World Bank (1977, p. 5) observes, the region has:

. . . free draining soils with a poor physical and chemical structure, heavily leached and of low fertility; good soils cover only an estimated one percent of the total area. Because of this, shifting agriculture (Chitemene) is practiced throughout the region. The long rainy season favors annual crops with a long growing season but the high rainfall, low sunshine hours, and low average temperature generally makes the area less favorable for crops grown elsewhere such as maize, cotton and tobacco. Because of the prevalence of the tsetse fly, much of the area is unsuited for cattle. The area, being generally frost-free, is more favorable for horticulture and for the development of timber (especially as the transport network improves) and tree crops (coffee, tea, citrus and other fruits).
Clearly, solutions to shifting agriculture in Zambia have yet to be devised. As a result, deforestation is a significant factor in sparsely populated provinces just as in the densely populated provinces in which the largest urban areas are located.

There is also the system of land tenure which acts as a catalyst to deforestation. The fact is, concepts of common property and open access apply to the system of land tenure in Zambia. This system of tenure is illustrated in Table 6.4.

In essence, the system of land tenure in Zambia is three-fold, it consists of: (1) State Land, (2) Trust Land, and (3) Reserves. This is a legacy of British rule, after Zambia became a British Protectorate in 1924 (Appendix A). Prior to that, tribal customs and conventions governed communal rights to land. However, in 1928, the British administration created a dual system of land tenure consisting of: (1) Crown Land and (2) Native Reserves (Dorner and Bruce, 1982). Crown Land consisted of land set aside for European settlement and was administered under English law, with freehold titles. Native Reserves consisted of land set aside for African residents and was administered under customary law, with communal rights to land.

The dual system of land tenure was designed to encourage European settlements into Northern Rhodesia, as Zambia was called at the time. However, European settlements turned out to be less than expected and, therefore, large portions of Crown Land remained idle. Meanwhile, population in the Native Reserves grew and put pressure on the carrying capacity of the Reserves. Land scarcity in the Reserves grew and
Table 6.1. Summary description of the vegetation of Zambia

<table>
<thead>
<tr>
<th>TYPE</th>
<th>I. CLOSED FOREST:</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>CLIMATIC</td>
</tr>
<tr>
<td></td>
<td>1. Low and medium altitude forest</td>
</tr>
<tr>
<td></td>
<td>a. Dry evergreen forest</td>
</tr>
<tr>
<td></td>
<td>i. Parinari forest and Copperbelt Chipya</td>
</tr>
<tr>
<td></td>
<td>ii. Marquesia forest</td>
</tr>
<tr>
<td></td>
<td>iii. Lake Basin Chipya</td>
</tr>
<tr>
<td></td>
<td>iv. Cryptosepalum forest</td>
</tr>
<tr>
<td></td>
<td>v. Kalahari Sand Chipya</td>
</tr>
<tr>
<td></td>
<td>b. Dry deciduous forest</td>
</tr>
<tr>
<td></td>
<td>i. Baikiaea forest and deciduous thicket</td>
</tr>
<tr>
<td></td>
<td>ii. Itigi forest</td>
</tr>
<tr>
<td></td>
<td>2. High altitude forest</td>
</tr>
<tr>
<td></td>
<td>a. Montane forest</td>
</tr>
<tr>
<td>B.</td>
<td>EDAPHIC</td>
</tr>
<tr>
<td></td>
<td>1. Swamp forest</td>
</tr>
<tr>
<td></td>
<td>2. Riparian forest</td>
</tr>
</tbody>
</table>

II. OPEN FOREST WITH GRASS

A. WOODLAND

1. Miombo woodland

a. On plateau escarpment and valley soils

b. On hills and rock outcrops

2. Kalahari woodland on sands

3. Mopane woodland on clays

4. Munga woodland on heavy soils

III. TERMITARY VEGETATION AND BUSH GROUPS

16 Termitary associated vegetation, and bush groups within grassy drainage zones

IV. GRASSLANDS

17 All naturally treeless and grassy areas, comprising mountain and watershed grassland Kalahari - sand plain, dambo, flood plain, swamp and papyrus sudd.

V. OPEN WATER

Source: Chakanga and de Backer (1986).
Table 6.2. Major types of forest and woodland in Zambia

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>% Wooded Area</th>
<th>% Total Land Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miombo</td>
<td>58</td>
<td>47</td>
</tr>
<tr>
<td>Kalahari</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Mopane</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Munga</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Cryptosepalum</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Lake Basin Chipya</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Baikiaea (Zambian Teak)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>94</strong></td>
<td><strong>76</strong></td>
</tr>
</tbody>
</table>

Table 6.3. Regional distribution of population, forest and woodland in Zambia

<table>
<thead>
<tr>
<th>Province</th>
<th>% of total population</th>
<th>% of total forest and woodland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copperbelt</td>
<td>23</td>
<td>6</td>
</tr>
<tr>
<td>Lusaka</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>Southern</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>Northern</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>Eastern</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Central</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Western</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>Luapula</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>North Western</td>
<td>5</td>
<td>25</td>
</tr>
</tbody>
</table>

Sources: Chakanga and de Barker (1986); World Bank (1988).
intensified. Thus, in 1938, an official inquiry into the system (the Pimm Commission) stated that the Reserve system was a failure. Therefore, in 1947, the British administration created a new and third category of land ownership: Trust Land. This category consisted of previously unassigned land and some of the idle Crown Land. Trust Land was set aside for Africans just as the Native Reserves, but Trust Land was to be settled by Africans on a non-tribal basis, unlike the case with Native Reserves. Thus, in 1964, when the British Protectorate of Northern Rhodesia became an independent republic under the name of Zambia, the land tenure was three-fold, consisting of: (1) Crown Land, (2) Trust Land, and (3) Native Reserves. Under the new republic, Crown Land became State Land, hence the present system of a three-fold tenure consisting of: (1) State Land, (2) Trust Land, and (3) Reserves.

It is, therefore, the case that the present system of land tenure in Zambia is a product of various legislation some of which are: The Zambia (State Land and Reserves) Orders, 1928 to 1964, the Zambia (Trust Land) Orders, 1947-1964, and Land (Conversion of Titles) Act of 1975 (Republic of Zambia, 1985c, 1987a). Thus, the Land (Conversion of Titles) Act of 1975 is the only major legislation on land tenure that the government has instituted since 1964. The Act (Republic of Zambia, 1987, p. 1) in part states that: "Notwithstanding anything to the contrary contained in any other law, deed, certificate, agreement or other instrument or document, but subject to the provisions of this Act all land in Zambia shall vest absolutely in the President and shall be held by him in perpetuity for and on behalf of the people of Zambia." In other words, by the Land
(Conversion of Titles) Act of 1975, all land in Zambia is communally owned by the people of Zambia, with the President as custodian of the land.

The President, however, has delegated the administration of the land to certain agencies. He has delegated the administration of State Land to the Commissioner of Lands, who, in turn, administers the land through renewable leases of 100 years a term. Under this system of leases, land is not sold but merely leased and transferred from one leaseholder to another without compensation. Improvements on land such as buildings, fixtures and fittings are sold. The main reason land is not sold is the government’s philosophy of creating a humanist society in Zambia. It is also argued that benefits from values in land belong to society as a whole while improvements on land belong to the individual who works a given piece of land (Dorner and Bruce, 1982). Benefits accruing from values in land are either created by nature or by actions of government on behalf of the people. It is the case, for instance, some land will be more fertile and, therefore, more valuable than some other piece of land. This is value imputed by nature. It is also the case that some land will be in close proximity to such infrastructure as roads, dams and bridges, and therefore will be in greater demand and more valuable than some other piece of land. This is value in the land imputed by actions of government on behalf of the people. It is, therefore, argued that land should not be sold because values in land belong to society as a whole, but improvements should be sold because improvements on land belong to the individual who works a given piece of land.
In practice, however, only Trust Land and Reserves are common property. The President has retained the provision in the old law which delegated the administration of Trust Land and Reserves to tribal chiefs. Thus, Trust Land and Reserves are communal lands administered by tribal authorities under customary law. However, as custodian of the land, the President can make grants or dispositions of land in Trust Land to Zambians and non-Zambians. The President can also make grants or dispositions of land in Reserves for periods of up to 99 years to Zambians and district councils, a period of 33 years in the case of a missionary society or a charitable organization, and for a period of no more than five years in any other case.

It is to be noted that much of the total area of Zambia of 75.3 million hectares falls under Trust Land and Reserves. According to government account (Republic of Zambia, 1987), the present distribution of land in Zambia is as follows:

<table>
<thead>
<tr>
<th>Type</th>
<th>Area (million ha.)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>State Land</td>
<td>4.5</td>
<td>6%</td>
</tr>
<tr>
<td>Trust Land</td>
<td>43.5</td>
<td>58%</td>
</tr>
<tr>
<td>Reserves</td>
<td>27.3</td>
<td>36%</td>
</tr>
</tbody>
</table>

It is the case then that 80.8 million hectares or 94% of the total land area in Zambia is common property in the strict sense of the term. However, as already indicated, not all land in Zambia is under forest and vegetation cover; there are an estimated 50 million hectares of forest and woodland or 66% of the total land area in Zambia. The forest and woodland are found in all three categories of land, but not all 50
Table 6.4. The system of land tenure in Zambia with an example of land distribution in 1973 (in hectares)

<table>
<thead>
<tr>
<th>Description</th>
<th>Area (hectares)</th>
</tr>
</thead>
<tbody>
<tr>
<td>State Land</td>
<td></td>
</tr>
<tr>
<td>Alienated in Freehold</td>
<td>1,015,791</td>
</tr>
<tr>
<td>Alienated in Leasehold</td>
<td>1,284,788</td>
</tr>
<tr>
<td>State Land under Tribal Occupation</td>
<td>509,396</td>
</tr>
<tr>
<td>Unalienated State Land</td>
<td>125,102</td>
</tr>
<tr>
<td>Inundated by Water</td>
<td>216,250</td>
</tr>
<tr>
<td>Forest Reserves</td>
<td>546,470</td>
</tr>
<tr>
<td>Protracted Forest Areas</td>
<td>382,750</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4,080,547</strong></td>
</tr>
</tbody>
</table>

| Reserved (including 689,691 ha Protected Forest Areas)   | 27,314,000      |

| Trust Land (including 4,250,889 ha. Protected Forest Areas and 29,153 ha. Forest Reserves) | 38,977,530 |

| National Parks, etc.                                     | 5,826,300      |

| **Total Land Area**                                      | **76,198,377** |

Source: Dorner and Bruce (1982).

Million hectares are under state protection by law. The level of state protection (World Bank, 1988) is as follows:

- **Protected State Forest:** 7.4 million ha. or 15%
- **Industrial Forest and Plantations:** 59,000 ha. or 1%
- **Other Forests:** 2 million ha. or 5%
- **Unprotected Forests:** 40 million ha. or 80%

It is the case then that 40 million hectares or 80% of the 50 million hectares of forest and woodland are not protected by law. In
other words, concepts of common property and open access apply to 80% of the forest and woodland in Zambia. However, it may be argued that harvesting wood for fuel is not a problem if the significant portion of the wood for fuel is harvested on the 10 million hectares or 20% of the protected forest and woodland. But this is not the case. The significant portion of wood for fuel is harvested on the 40 million hectares of unprotected forest and woodland. It is, for instance, estimated that only 5% of the charcoal is made by producers using sources of wood licensed by the Forest Department (World Bank, 1988). The other 95% of supply is from forest and woodland under customary law in Trust Land and Reserves.

Therefore, under the existing system of property rights, it is predictable that there will be a sub-optimal use of the wood resource. It is quite conceivable that the existing system of property rights gives rise to what in modern economic theory is referred to as the "free rider" problem (Mueller, 1979). As noted earlier, one of the characteristics of a common property resource is open access to the resource by all those who care to use the resource. In other words, the use of the common property resource is nonexcludable. It may be impossible or at least very costly to exclude particular individuals from the use of the common property resource. For instance, in the case of woodfuel production, the transaction costs of collecting stumpage fees and taxes may be too excessive to enforce the requirements for stumpage fees and taxes on common property forest and woodland. On the other hand, because of nonexcludability, national firewood collectors and charcoal producers
will not voluntarily pay stumpage fees and taxes but will use the wood resource free of charge, that is, they will behave as free riders.

Then, according to the theory of exhaustible resources, there are several predictable consequences when woodfuel producers behave as free riders. First, the market price of woodfuel does not reflect the economic cost of the wood resource; rather, the market price is lower than the economic cost of the wood resource. This discourages tree planting. Second, the cost of cooking with woodfuel is relatively lower than other energy sources. This encourages woodfuel consumption. However, since there is less incentive to plant trees, the stock of the wood resource, and therefore consumption should be declining over time.

These results can be shown by equations (6.11) and (6.44) above. From equation (6.11), the market price of woodfuel may be defined as:

\[ P_t = C + \lambda(1+r)^t \]  

(6.47)

where all the terms are as defined before. With common property forest and woodland, and given the free rider problem, extraction costs, C, are zero or negligible. Similarly, with no tree planting or forest management, user costs, \( \lambda(1+r)^t \), are zero or negligible. Therefore, the market price is lower than would otherwise be the case; rather, the price reflects only such things as labor cost and transport cost but not stumpage fees and taxes, and not the economic cost of producing or regenerating the wood resource.

From equation (6.44), the consumption of woodfuel over time may be defined as:
\[
\frac{dU'(C)}{U'(C)} = \frac{d}{dt} - r - F_K
\]  

(6.48)

where all the terms are as defined before. In this case, \( F_K \) is zero or negligible because there is less incentive to regenerate the wood resource under common property, and also given the free rider problem. Therefore, \( \frac{[dU'(C)/d_t]}{U'(C)} \) is greater than zero, and, therefore, consumption must be declining over time.

Several factors indicate that these results apply in the case of Zambia (Cheatle and Cheatle, 1981; Chidumayo, 1990a; FAO, 1986b; Taylor, 1990; World Bank, 1988, 1990). These factors include:

1. lack of management of the wood resource; most of the manpower of the forest service is engaged in logging, transportation and processing of the wood resource.
2. very quick and unreliable assessment and, therefore, gross-underestimation of the value of the wood resource for purposes of levying stumpage fees and taxes.
3. under-collection of stumpage fees and taxes due to the inability of the forest service to adjust stumpage fees and taxes to reflect the value of wood and due to lack of manpower.
4. under-financing of the forest service and, therefore, low pay for staff members and also lack of equipment, transport and training; all factors leading to low morale among staff members.

More specifically, the Zambian government levies a stumpage fee of K8 per cord of wood harvested on state protected forests. The government
also levies various taxes on forest products. For instance, there is a "removal" tax on charcoal of K0.50 per bag. According to the World Bank (1990, p. 31) study on urban household energy supply and demand: "The trade in wood products, particularly charcoal, is sufficient to finance the forest service if economic stumpage fees are charged and if the fees are fully collected." However, the World Bank observes, due to the problems outlined above, the fees are under-collected. The study cites the example of 1987 when the collected fees from all forest products amounted to only K2.8 million when stumpage fees on traded firewood and charcoal in the urban areas alone should have raised an estimated K20 million; reflecting an under-collection of the fees by K17.2 million. Similarly, Chidumayo (1990, p. 6) observes that "... the government is losing two-thirds of its revenue through inadequate inventory work."

In another study, the World Bank (1988) shows that the market price of charcoal does not reflect the economic cost of the wood resource. The World Bank makes the following calculations of the cost structure of charcoal production for 1986 in gigajoules (GJ):

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost (GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of planting wood</td>
<td>K3.1/GJ</td>
</tr>
<tr>
<td>Cost of charcoal production</td>
<td>K3.6/GJ</td>
</tr>
<tr>
<td>Total economic cost</td>
<td>K6.6/GJ</td>
</tr>
<tr>
<td>Transport cost</td>
<td>K4.6/GJ</td>
</tr>
<tr>
<td>Total cost</td>
<td>K11.2/GJ</td>
</tr>
<tr>
<td>Market price of charcoal</td>
<td>K6.2/GJ</td>
</tr>
</tbody>
</table>
Table 6.5. Comparative economic costs of cooking with different fuels in Zambia

A. Estimated economic cost in Kwacha per gigajoule

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Estimated average cooking efficiency</th>
<th>Cost of cooking, assuming value of foreign exchange is:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K10/US$</td>
<td>K25/US$</td>
</tr>
<tr>
<td>Charcoal</td>
<td>15%</td>
<td>220-250</td>
</tr>
<tr>
<td>Kerosene</td>
<td>35%</td>
<td>260</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home with connection(1)</td>
<td>60%</td>
<td>170-220</td>
</tr>
<tr>
<td>Home requiring connection(2)</td>
<td>60%</td>
<td>330-380</td>
</tr>
</tbody>
</table>

B. Ratio of the cost of cooking with alternative fuels to the cost of cooking with charcoal (Cost of alternative fuel/Charcoal Cost)

<table>
<thead>
<tr>
<th>Fuels</th>
<th>March 1989 cost paid by consumers</th>
<th>Economic cost (at K25/US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerosene</td>
<td>0.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home with connection(1)</td>
<td>0.5</td>
<td>0.9-1.3</td>
</tr>
<tr>
<td>Home requiring connection(2)</td>
<td>0.7</td>
<td>1.9-2.1</td>
</tr>
</tbody>
</table>

(1) Ranges show values for different hot plates.

(2) Includes cost of wiring for a 2-room home and connection 30m from the grid, prorated by the share of cooking consumption in total anticipated power use.

Clearly then, the market price of charcoal in 1986 was only about half the total cost of production. On the other hand, Taylor (1990), shows that it is relatively cheaper to cook with charcoal than with kerosene or electricity (Table 6.5). Under these conditions then, it is to be expected that woodfuel consumption will decline over time unless efforts are made to regenerate the wood resource.
CHAPTER VII. SUMMARY AND CONCLUSIONS

The significance of biomass energy in developing countries continues to attract a great deal of attention. The main reason for this is that, in many of the developing countries, the rural and urban poor face acute shortages of traditional biomass fuels because of the combined effects of increasing demand and diminishing supplies of traditional fuels. This crisis is attributed to several factors. On the demand side, the increase in demand is considered to be a result of population growth, but also aggravated by urbanization and increased oil prices which make alternative fuels unaffordable to the rural and urban poor. On the supply side, the decrease in supplies is considered to be a result of deforestation. In turn, deforestation is known to be a result of four principal factors: (1) clearing of land for agriculture, (2) overgrazing by animals, (3) timber removal, and (4) wood energy production.

This study examines the status of biomass energy in Zambia. In its current usage, the concept of biomass energy often implies woodfuel because woodfuel is the main biomass energy. In Zambia, woodfuel is the main biomass energy, estimated to account for 84 percent of total household energy consumption, and 64 percent of Zambia's total energy supply.

This study develops an econometric model of household woodfuel demand in Zambia. The study finds that in both the rural and urban sectors, inflation is by far the most significant determinant of household woodfuel demand. In both sectors, the coefficients on inflation are
significant at better than the one percent level and have plausible positive signs.

The overriding effect of inflation on household woodfuel demand can be traced to the simultaneous occurrence of inflation and recession in Zambia since the 1973 oil crisis. This situation of inflationary recession is often described as stagflation and discourages substitution in consumption from woodfuel to commercial sources of energy such as electricity and kerosene.

However, outside the factor of inflation, there are significant sectoral differences in woodfuel demand between the rural and urban sectors. In the rural sector, income and energy prices are not significant determinants of household woodfuel demand. This seems to be because woodfuel consumption in the rural sector is largely outside the monetary economy. Almost all wood is collected for own-use, very little is traded. But this is not the case in the urban sector: household income and woodfuel price are significant determinants of demand. The coefficients on household income, and woodfuel price are all significant at better than one percent level and have expected signs.

The positive income elasticity of demand suggests that, in the short-run, woodfuel is a normal good. However, the model indicates that in the long-run, woodfuel is an inferior good. This can be seen from the negative correlation of woodfuel demand to the structural variable, growth in investment.

This study also briefly reviews the supply of woodfuel in Zambia. The reviews indicate that there is a negative correlation of population
to vegetation cover: densely populated areas have fewer forests and woodlands; and the opposite is equally true. As a result, there are regions of localized deforestation, especially those surrounding urban areas and principal areas of commercial agriculture.

The review also indicates that woodfuel supply is severely constrained by weather, transportation, and technology. On the other hand, these supply shift factors have an indirect or spurious effect on woodfuel demand, through prices. Seasonality in woodfuel supply introduces seasonality in woodfuel prices; the prices being higher during the rainy season.

However, woodfuel prices do not reflect the economic cost of the wood resource for several reasons, but mainly due to the institution of common property and open access to woodlands and forests. The low prices are a disincentive to tree planting but a stimulus to woodfuel consumption.

Therefore, based on these observations about wood energy supply and demand in Zambia, the recommendations of this study are in four principal areas: (1) management, (2) conservation, (3) production, and (4) substitution.

1. Management

There is need to spread out or extend the harvesting of woodfuel to remote areas. This requires improved roads and other infrastructures, establishing an annual cut to allow the woodlands time to regenerate, combining logging with cutting woodlands for energy, and letting the local people do the logging and cutting for energy. However, the forest
service should still play an active role, including: (1) generating awareness among the local people on the consequences of deforestation, (2) advising the local people when to optimally harvest wood to maximize re-growth, (3) prevent over-cutting, and (4) collect stumpage fees and taxes. In this way, both the local people and the government gain from increased employment, income, revenue and stable source of energy. Meanwhile, the revenue realized by the government from the stumpage and removal fees is to be retained by the Forest Department as a special fund to meet the recurrent and developmental costs of the forest service; for instance, in funding research and development in the Faculty of Forestry which is suggested here to be established at the University of Zambia.

2. Conservation

Conservation of the wood resource is in three main ways: (1) the use of improved cooking stoves, (2) the use of improved technology in the conversion of wood into charcoal, and (3) the use of efficient methods of wood harvesting. For instance, improved efficiency in harvesting would require converting logging residues into charcoal. It is also the case that introduction of improved technology in woodfuel production and use requires improved extension services; for instance, employment of more women in the forest service.

3. Production

One of the major constraints to the use of biomass energy is the competition for land between food and fuel production. However, the notion of comparative advantage suggests that areas near the main population centers have a comparative advantage in food production
because of such factors as minimum storage costs and waste in food production. Therefore, these areas seem to be best suited for agricultural food production. On the other hand, some land under trees cannot sustain agriculture and should, therefore, not be converted into cropland. This is clearly the case in regions where shifting cultivation is presently practiced. The soils in these areas are poor and acidic; yet these lands capable of marginal crop production are suited for biomass production because they receive the highest rainfall in Zambia. What is required is, therefore, to spread logging and woodfuel production to these areas. Rather, what is required is planned rational use of land by the government in cooperation with local authorities.

4. **Substitution**

Substitution is to be encouraged, from woodfuel consumption to commercial fuels, mainly electricity, and to a lesser degree, kerosene. This requires the use of woodfuel prices as a rationing device; raising woodfuel prices to reflect the economic cost of the wood resource, to discourage woodfuel consumption, and to encourage woodfuel production. However, there can be no long-term reduction in woodfuel demand without concomitant increases in income and investment. This is because long-term reduction in woodfuel demand is negatively related to the structure of the economy or growth in investment. It, therefore, follows that both the supply and demand for wood as a source of energy in Zambia are an integral part of national development.
LITERATURE CITED


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Zambia was born out of a vast mining complex, primarily that of copper. Even though David Livingstone and other nineteenth century European explorers realized the potential of the region, it was John Cecil Rhodes, however, who through the British South Africa Company, brought it under British influence. In 1891, the Company divided the region into two administrative units: North-Western and North-Eastern Rhodesia. Northern Rhodesia was created in 1911 when the two territories were amalgamated. In 1924, it became a British Protectorate when the Imperial Government took over the administration from the Company. Together with Southern Rhodesia and Nyasaland, on August 31, 1953, Northern Rhodesia formed the Federation of Rhodesia and Nyasaland--also known as the Central Africa Federation. This was dissolved on December 31, 1963. And on October 24, 1964, the British Protectorate of Northern Rhodesia became an independent republic under the name of Zambia.
APPENDIX B. MACROECONOMIC INDICATORS OF THE ZAMBIAN ECONOMY: REAL GDP, GDP GROWTH RATES, INVESTMENT AND POPULATION

<table>
<thead>
<tr>
<th>Year</th>
<th>Real GDP (millions of K)</th>
<th>GDP growth rates</th>
<th>Investment (millions of K)</th>
<th>Population (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>1618</td>
<td>-</td>
<td>57.2</td>
<td>3.60</td>
</tr>
<tr>
<td>1965</td>
<td>1915</td>
<td>0.16853</td>
<td>155.9</td>
<td>3.70</td>
</tr>
<tr>
<td>1966</td>
<td>2172</td>
<td>0.12593</td>
<td>226.2</td>
<td>3.83</td>
</tr>
<tr>
<td>1968</td>
<td>2632</td>
<td>0.07206</td>
<td>320.7</td>
<td>4.05</td>
</tr>
<tr>
<td>1969</td>
<td>3123</td>
<td>0.17105</td>
<td>238.0</td>
<td>4.06</td>
</tr>
<tr>
<td>1970</td>
<td>2695</td>
<td>-0.14740</td>
<td>338.0</td>
<td>4.18</td>
</tr>
<tr>
<td>1971</td>
<td>2697</td>
<td>0.00074</td>
<td>416.0</td>
<td>4.30</td>
</tr>
<tr>
<td>1972</td>
<td>2962</td>
<td>0.09372</td>
<td>421.0</td>
<td>4.42</td>
</tr>
<tr>
<td>1973</td>
<td>2934</td>
<td>-0.00950</td>
<td>459.0</td>
<td>4.68</td>
</tr>
<tr>
<td>1974</td>
<td>3132</td>
<td>0.06531</td>
<td>692.0</td>
<td>4.83</td>
</tr>
<tr>
<td>1975</td>
<td>3056</td>
<td>-0.02456</td>
<td>642.0</td>
<td>4.98</td>
</tr>
<tr>
<td>1976</td>
<td>3187</td>
<td>0.04197</td>
<td>452.0</td>
<td>5.14</td>
</tr>
<tr>
<td>1977</td>
<td>3035</td>
<td>-0.04887</td>
<td>490.0</td>
<td>5.30</td>
</tr>
<tr>
<td>1978</td>
<td>3067</td>
<td>0.01049</td>
<td>537.0</td>
<td>5.47</td>
</tr>
<tr>
<td>1979</td>
<td>2975</td>
<td>-0.03046</td>
<td>576.0</td>
<td>5.65</td>
</tr>
<tr>
<td>1980</td>
<td>3064</td>
<td>0.02948</td>
<td>701.0</td>
<td>5.83</td>
</tr>
<tr>
<td>1981</td>
<td>3253</td>
<td>0.05986</td>
<td>673.0</td>
<td>5.83</td>
</tr>
<tr>
<td>1982</td>
<td>3161</td>
<td>-0.02869</td>
<td>603.0</td>
<td>6.03</td>
</tr>
<tr>
<td>1983</td>
<td>3099</td>
<td>-0.01981</td>
<td>575.0</td>
<td>6.24</td>
</tr>
<tr>
<td>1984</td>
<td>3058</td>
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APPENDIX C. MACROECONOMIC INDICATORS OF THE ZAMBIAN ECONOMY: REAL GDP, REAL PER CAPITA GDP, INVESTMENT/GDP AND SAVINGS/GDP RATIOS

<table>
<thead>
<tr>
<th>Year</th>
<th>Real GDP (millions of kwacha)</th>
<th>Real GDP per capita</th>
<th>Share in GDP of</th>
<th>Investment</th>
<th>Savings</th>
<th>Imports</th>
<th>Exports</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Investment %</td>
<td>Savings %</td>
<td>Imports %</td>
<td>Exports %</td>
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</tr>
<tr>
<td>1964</td>
<td>1,618</td>
<td>449</td>
<td>11.4</td>
<td>38.4</td>
<td>42.6</td>
<td>82.0</td>
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<tr>
<td>1965</td>
<td>1,915</td>
<td>518</td>
<td>24.5</td>
<td>39.9</td>
<td>37.0</td>
<td>56.0</td>
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<tr>
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<td>572</td>
<td>28.9</td>
<td>43.0</td>
<td>39.5</td>
<td>57.7</td>
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</tr>
<tr>
<td>1967</td>
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<td>628</td>
<td>30.8</td>
<td>36.9</td>
<td>43.5</td>
<td>52.4</td>
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<tr>
<td>1968</td>
<td>2,632</td>
<td>650</td>
<td>32.4</td>
<td>39.3</td>
<td>44.3</td>
<td>54.0</td>
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<tr>
<td>1969</td>
<td>3,123</td>
<td>758</td>
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<td>51.4</td>
<td>32.4</td>
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<tr>
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<td>2,695</td>
<td>634</td>
<td>28.4</td>
<td>45.4</td>
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<td>614</td>
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<td>35.1</td>
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<td>654</td>
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<td>36.9</td>
<td>41.9</td>
<td>46.0</td>
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<td>2,934</td>
<td>627</td>
<td>29.2</td>
<td>45.0</td>
<td>33.2</td>
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<td>1974</td>
<td>3,132</td>
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<td>46.0</td>
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<tr>
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<tr>
<td>1977</td>
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<td>573</td>
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<tr>
<td>1978</td>
<td>3,067</td>
<td>561</td>
<td>23.9</td>
<td>20.5</td>
<td>36.9</td>
<td>32.8</td>
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<tr>
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<td>23.1</td>
<td>36.5</td>
<td>44.0</td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>3,064</td>
<td>526</td>
<td>23.3</td>
<td>19.3</td>
<td>45.4</td>
<td>39.6</td>
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</tr>
<tr>
<td>1981</td>
<td>3,253</td>
<td>558</td>
<td>19.3</td>
<td>6.8</td>
<td>41.1</td>
<td>27.7</td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>3,161</td>
<td>524</td>
<td>16.9</td>
<td>8.0</td>
<td>36.5</td>
<td>27.3</td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>3,099</td>
<td>497</td>
<td>13.8</td>
<td>12.6</td>
<td>31.8</td>
<td>30.6</td>
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</tr>
<tr>
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<td>3,058</td>
<td>474</td>
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<td>1964-74</td>
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<td>614</td>
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<td>41.6</td>
<td>39.7</td>
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<td>1974-84</td>
<td>3,099</td>
<td>557</td>
<td>22.9</td>
<td>20.7</td>
<td>39.9</td>
<td>36.6</td>
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APPENDIX D. 1988 ENERGY BALANCE FOR URBAN HOUSEHOLDS\textsuperscript{a} IN ZAMBIA, TONNES OIL EQUIVALENT (TOE) AND PETAJOULES (PJ) IN PARENTHESES

<table>
<thead>
<tr>
<th></th>
<th>Cooking</th>
<th>Water Heating</th>
<th>Space Heating</th>
<th>Cooling</th>
<th>Ironing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charcoal</td>
<td>186,600</td>
<td>62,580</td>
<td>96,701</td>
<td>--</td>
<td>25,030</td>
</tr>
<tr>
<td></td>
<td>(7.98)</td>
<td>(2.67)</td>
<td>(4.13)</td>
<td>--</td>
<td>(1.07)</td>
</tr>
<tr>
<td>Firewood\textsuperscript{b}</td>
<td>86,880</td>
<td>28,210</td>
<td>40,060</td>
<td>--</td>
<td>12,130</td>
</tr>
<tr>
<td></td>
<td>(3.71)</td>
<td>(1.21)</td>
<td>(1.71)</td>
<td>--</td>
<td>(0.52)</td>
</tr>
<tr>
<td>Crop Residues</td>
<td>14,330</td>
<td>7,1670</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>(0.61)</td>
<td>(0.31)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Electricity</td>
<td>25,650</td>
<td>2,290\textsuperscript{c}</td>
<td>2,070</td>
<td>130</td>
<td>2,290</td>
</tr>
<tr>
<td></td>
<td>(1.10)</td>
<td>(0.10)</td>
<td>(0.09)</td>
<td>(0.00)</td>
<td>(0.10)</td>
</tr>
<tr>
<td>Kerosene</td>
<td>3,110</td>
<td>260</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>(0.13)</td>
<td>(0.01)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>TOTAL</strong>\textsuperscript{d}</td>
<td>316,570</td>
<td>100,500</td>
<td>138,840</td>
<td>130</td>
<td>39,450</td>
</tr>
<tr>
<td></td>
<td>(13.53)</td>
<td>(4.30)</td>
<td>(5.93)</td>
<td>(0.00)</td>
<td>(1.69)</td>
</tr>
</tbody>
</table>

Percentage: 50 16 22 0 6

\textsuperscript{a} 528,000 households; 2,966,000 people - 40\% of Zambia's population.

\textsuperscript{b} Excluding firewood used in funerals estimated at 16,000 TOE (43,000 tons) which when added brings the total household energy consumption to about 656,000 TOE.

\textsuperscript{c} Geysers for water heating only.

\textsuperscript{d} This table does not take into consideration end use efficiency.
<table>
<thead>
<tr>
<th>TV</th>
<th>Fridge</th>
<th>Lighting</th>
<th>Fire Ignition</th>
<th>Other</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>1,140</td>
<td>372,060</td>
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<td>--</td>
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<td>--</td>
<td>--</td>
<td>(0.05)</td>
<td>(15.90)</td>
</tr>
<tr>
<td></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>570</td>
<td>167,850</td>
</tr>
<tr>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>(0.02)</td>
<td>(7.17)</td>
</tr>
<tr>
<td></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>21,490</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>(0.92)</td>
<td></td>
</tr>
<tr>
<td>630</td>
<td>2,830</td>
<td>9,030</td>
<td>--</td>
<td>--</td>
<td>44,920</td>
<td>7</td>
</tr>
<tr>
<td>(0.03)</td>
<td>(0.12)</td>
<td>(0.38)</td>
<td></td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--</td>
<td>--</td>
<td>18,060</td>
<td>9,000</td>
<td>3,300</td>
<td>33,730</td>
<td>5</td>
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<tr>
<td>--</td>
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<td>(0.78)</td>
<td>(0.38)</td>
<td>(0.14)</td>
<td>(1.44)</td>
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<tr>
<td>630</td>
<td>2,830</td>
<td>27,090</td>
<td>9,000</td>
<td>5,010</td>
<td>640,050</td>
<td>100</td>
</tr>
<tr>
<td>(0.03)</td>
<td>(0.12)</td>
<td>(1.16)</td>
<td>(0.38)</td>
<td>(0.21)</td>
<td>(27.35)</td>
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<tr>
<td>0</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
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APPENDIX E. 1988 ENERGY BALANCE FOR URBAN HOUSEHOLDS IN ZAMBIA (PERCENTAGES)

<table>
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<tr>
<th></th>
<th>Cooking</th>
<th>Water Heating</th>
<th>Space Heating</th>
<th>Cooling</th>
<th>Ironing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Charcoal</strong></td>
<td>50</td>
<td>17</td>
<td>26</td>
<td>--</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(59)</td>
<td>(62)</td>
<td>(70)</td>
<td>(63)</td>
<td></td>
</tr>
<tr>
<td><strong>Firewood</strong></td>
<td>52</td>
<td>17</td>
<td>24</td>
<td>--</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(27)</td>
<td>(28)</td>
<td>(29)</td>
<td>(31)</td>
<td></td>
</tr>
<tr>
<td><strong>Crop</strong></td>
<td>67</td>
<td>33</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Residues</strong></td>
<td>(5)</td>
<td>(7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electricity</strong></td>
<td>57</td>
<td>5</td>
<td>5</td>
<td>--</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>(8)</td>
<td>(2)</td>
<td>(1)</td>
<td>(100)</td>
<td>(100)</td>
</tr>
<tr>
<td><strong>Kerosene</strong></td>
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<td>1</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(1)</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

% TOTAL       | (100)   | (100)         | (100)         | (100)   | (100)   |

\(^a\)Calculated on the basis of Appendix D.
<table>
<thead>
<tr>
<th>TV</th>
<th>Fridge</th>
<th>Lighting</th>
<th>Fire Ignition</th>
<th>Other</th>
<th>Total</th>
<th>%</th>
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<tbody>
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<td>--</td>
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<td>--</td>
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<td>100</td>
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<tr>
<td>2</td>
<td>6</td>
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<td>100</td>
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<tr>
<td>(100)</td>
<td>(100)</td>
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<td>(100)</td>
<td>(67)</td>
<td>(100)</td>
<td>(100)</td>
<td>(66)</td>
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<tr>
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