To the Graduate Council:

I am submitting herewith a dissertation written by Eiman Osman Zeinelabdin entitled "The Impact of Improved Cookstoves on the Demand for Fuel Wood in Sub-Saharan Africa, and its Relation to Deforestation." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Economics.

Professor Milton Russell, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor
and Dean of the Graduate School

THE IMPACT OF IMPROVED COOKSTOVES ON THE DEMAND FOR FUEL WOOD IN SUB-SAHARAN AFRICA, AND ITS RELATION TO DEFORESTATION

A Dissertation

Presented for the

Doctor of Philosophy

Degree

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Eiman Osman Zeinelabdin

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DEDICATION

To my family

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ABSTRACT

Improved cooking stoves have been introduced over forty years ago to achieve a multiplicity of objectives, including containment of deforestation. This research has attempted to evaluate the experience of improved stoves in Sub-Saharan Africa in relation to the phenomenon of forest depletion, and to propose a procedure for calculating second order effects in the form of increased fuel purchases. The procedure is designed to economize on data requirements, which often prevent analysis of important issues in less developed countries. Three prerequisite conditions for evaluation of improved stoves are examined: first, the relation of biomass energy consumption to forest depletion; second, the ability of improved stoves to realize significant improvements in fuel burning efficiency and wide scale diffusion among households; and limited secondary purchases of fuel wood. Examination of these conditions indicated that improved stoves will be effective in slowing deforestation in Sub-Saharan Africa where fuel wood consumption contributes significantly to forest destruction. Results indicate that income-induced secondary purchases of fuel are modest, but purchases resulting from price adjustments are relatively large.

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Canoun El Surour	CES
Canoun El Jadid	CEJ
Canoun El Duga	CED
Carbon Dioxide	CO_2
Carbon Monoxide	CO
Care International Relief Organization	CARE
Centimeter	cm
Communauté Francaise Africaine Franc	CFAF
Chloroflurocarbons	CFCs
Cost, Insurance, and Freight	CIF
Cubic Meter	m^3
Food and Agriculture Organization of the United Nations	FAO
Forests National Corporation	FNC
Giga Joules	Gj
Gross Domestic Product	GDP
Gross National Product	GNP
Intermediate Technology Development Group	ITDG
International Monetary Fund	IMF
Kenya Ceramic Jiko Stove	KCJ

Kilogram	kg
Kilogram of Oil Equivalent	KGOE
Kilometer	km
Kenya Renewable Energy Development Project	KREDP
Less Developed Countries	LDCs
Liquified Petroleum Gas	LPG
Mega Joules	Mj
Methane gas	CH_4
Metric Tons	Mt
Millimeter	mm
Million	Mn
National Academy of Sciences	NAS
Nitrous Oxide	N_2O
Non-Governmental Organization	NGO
Oak Ridge National Laboratory	ORNL
Ordinary Least Squares Method	OLS
Organization of Petroleum Exporting Countries	OPEC
parts per million	ppm
Permanent Interstate Committee for Drought Control in the Sahel	CILSS
Sudan Energy Research Council	SERC
Sudan National Energy Administration	SNEA
Sudan Renewable Energy Project	SREP
Sudanese Pound	Ls

Tons of Oil Equivalent .... TOE

United Nations Children's Fund .... UNICEF

United Nations Development Program .... UNDP

United Nations Environment Program .... UNEP

United States Agency for
International Development .... USAID

Volunteers in Technical Assistance .... VITA

World Resources Institute .... WRI

Yule-Walker Auto-regressive Procedure .... Y-W

CHAPTER 1

INTRODUCTION

1. Background and Motivation

Environmental degradation and slow economic growth is a condition facing a large number of less developed countries.[1] Given the multitude of pressing development needs, there is little room for undertaking costly environmental protection programs. Under these conditions, the most appropriate type of policy is a multi-objective one that simultaneously deals with economic and environmental issues, thereby optimizing the use of resources. This dissertation addresses the efficacy of policies designed to slow deforestation in Sub-Saharan Africa, specifically, improved cooking stoves.[2]

Deforestation, alternatively forest depletion or destruction, is a common condition in less developed countries. It is estimated that the rate of reduction in

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[1] The term less developed countries, alternatively poor or developing countries, is used here in the conventional way it is used in the development literature to include the large group of countries differentiated from the major industrialized countries. In the World Bank classification system this includes all "low and middle income" countries, and the "high income" countries of Hong Kong, Israel, Kuwait, Singapore, and United Arab Emirates. Developed countries include Australia, Canada, Japan, the former Soviet Union, the US, and Western Europe, except Ireland and Portugal. See World Bank, 1992.

[2] Sub-Saharan Africa refers to all countries in Africa with the exception of South Africa, and the North African Arab states: Algeria, Egypt, Libya, Morocco, and Tunisia. Sub-Saharan Africa includes 28 out of the 42 countries designated by the United Nations Organization (UN) as "least developed" (UN 1990).

the area of forests around the tropics is at least 16 million hectares annually (WRI 1990-91, 292-93). This condition is mainly caused by expansion of the area under cultivation and heavy reliance on fuel wood, both driven by rapid population growth.[3] In Sub-Saharan Africa, over 90% of the population depends on wood energy (Anderson and Fishwick 1984, 1).

The most important result of forest and land degradation is the loss of agricultural productivity, where the removal of vegetation exposes the soil to erosion.[4] This is reflected in lower foreign exchange earnings, agriculture being the main source of income in poor countries. The social cost of deforestation is manifested in increased labor time required for collection of firewood in rural areas, and high fuel expenses in urban areas. In the African Sahel, the search for fuel wood occupies a substantial part of the day for rural households.[5] Reduction in the number of cooked meals in order to save fuel is cited as one of the causes of malnutrition in the region.

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[3] The term fuel wood is used here to refer to firewood and charcoal together. In some of the literature fuel wood is used synonymously with firewood. This is rather misleading.

[4] In areas of severe fuel wood scarcity, burning of crop residues and animal dung robs the soil of essential fertilizing nutrients.

[5] The Sahel is one of the ecological zones in Africa. It covers a narrow strip of land falling between the Sahara Desert and the Sudanian zone in the South. It includes parts of Southern Mauritania, and Mali, Northern Senegal, and Burkina Faso, and cuts across Niger, Chad, and The Sudan. It is characterized by low and erratic rainfall not exceeding 500 mm annually (De Vos 1975, 43-44).

The ecological consequences of deforestation are diverse. Soil erosion has already been mentioned. Increased flooding, particularly in mountainous areas, and high siltation have serious implications for irrigation systems and hydroelectric power generation.[6] Moreover, the loss of habitat in tropical forests affects tourism as another source of foreign exchange, and perhaps more seriously, threatens biological diversity. Finally, deforestation contributes to the phenomenon of global warming through the release of carbon during the decomposition of trees. The emission of greenhouse gases during the burning of fuel wood may also have an impact on global warming unless this is offset by tree growth.

Environmental concerns have been the main motivation behind the involvement of international organizations and governments in developed countries in efforts to preserve tropical forests.[7] But in less developed countries, it is the economic costs of deforestation that gave rise to official action. Nevertheless, there are still wide gaps in the current state of knowledge regarding causes and effects

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[6] In Colombia, the Achicaya dam lost one quarter of its storage capacity due to siltation in the first 21 months of its operation in 1955. By the end of the first decade, 75% was lost. In Pakistan, the expected life of the Tarbela dam, built in 1975, is a maximum 50 years because of siltation from deforested lands in the Himalayas (El Hinnawi and Hashmi 1987, 38).

[7] The United States (US) has been involved in this concern for some time. In 1978, the US Strategy Conference on Tropical Deforestation, jointly sponsored by the State Department and US Agency for International Development (USAID), and the Workshop on Firewood in Africa sponsored by USAID Africa Bureau, identified fuel wood and tropical deforestation as issues of considerable concern to the US. In 1979, the President of the US personally instructed the Administrator of USAID and the Director of the Peace Corps to give high priority to forestry programs and projects for increased production and conservation of firewood (Knowland and Ulinski 1979).

of forest disappearance. This prevents the selection of appropriate intervention strategies, which is critical in poor countries.

Improved cookstove programs are one of the policies adopted to contain forest destruction in less developed countries. Improved stoves were introduced in India almost half a century ago. Considerable resources have been invested in them. However, they have not yet lived up to expectations. Despite the wealth of stove literature, comprehensive evaluation of the experience is yet to be undertaken. Even though deceleration of deforestation is invariably stated as a major goal of stove programs, evaluation attempts have focused on other aspects.

The reason why improved stoves are believed to slow deforestation is that it is widely held that currently used stoves (from hereon traditional stoves) are wasteful in their use of fuel. The percentage of fuel wood energy actually utilized for the performance of different tasks ranges from 3-5% for the three-stone fire to 10-15% for charcoal stoves (Whitney et al 1987, 334). Based on this notion of low efficiency of traditional stoves, it is firmly held that simple modifications in the design of the traditional stove to improve combustion and insulation could easily double fuel efficiency.

In addition to containing deforestation, improved stoves are designed to fulfill an array of private and social goals. These include: 1) increasing income by reducing fuel requirements; 2) saving time both in firewood collection and in cooking, thereby freeing labor for other activities; 3) reduction of indoor air pollution, and the risk of burns and other health hazards associated with traditional cooking; and more recently, 4) reduction in greenhouse emissions.[8] It is believed that improved stoves offer the most cost-effective measure to reduce greenhouse emissions in Sub-Saharan Africa (ORNL 1990). These benefits add to the appeal of improved stoves as a multi-objective policy most suited for countries with severe resource constraints.

Some authors have questioned the impact of improved stoves on deforestation on the basis that the latter is mostly caused by agricultural expansion rather than by fuel wood consumption (Foley et al 1984). More recently, others have discounted the efficacy of improved stoves because they may result in large second order effects in the form of increased purchases of fuel wood by households (Murck et al 1985, Jones 1988).[9] These purchases are induced by increases in real income resulting from reduced fuel

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[8] Greenhouse gases released in the burning of wood are carbon dioxide, methane, and nitrous oxide. Pollutants generated by the burning of wood also include particulates, carbon oxides, hydrocarbons, nitrogen and sulphur oxides, and formaldehyde. Some particulates include a number of known carcinogens. The health effects of these pollutants are chronic pulmonary disease and nasopharyngeal cancer. Visual disorders have also been reported (Quraishi 1985). Children and infants are particularly exposed to these toxins (Smith 1985, 1993). Indoor air pollution in less developed countries has received relatively little attention.

[9] Throughout this document, unless otherwise stated, the efficacy or effectiveness of improved stoves pertains to reducing deforestation.

requirements.

This dissertation accomplishes two things: 1) it examines the validity of the above assertions within the framework of the market for fuel wood in Sub-Saharan Africa; 2) it proposes a procedure for calculation of the second order effects of improved stoves. The procedure economizes on data requirements, which is believed to be critical in light of the fact that data constraints often prevent analysis of important problems in poor countries. This is in departure from previous studies that impose excessive restrictions on market structure and or require too many parameters.

The null hypothesis tested here is that improved stove programs are effective in slowing down forest depletion in Sub-Saharan Africa. This statement is contingent upon three essential conditions, the violation of which falsifies the hypothesis. The first condition is the presence of a relation between fuel wood consumption and forest destruction, such that decreasing fuel wood consumption through the use of more fuel efficient stoves will reduce deforestation.

The second condition has to do with the ability of improved stoves to raise fuel burning efficiency, and to be accepted by users on a large scale in order to generate a significant impact on aggregate fuel wood consumption. This condition includes the technical design or fuel efficiency of improved stoves and wide dissemination within a specific social and institutional framework.

The final test of the efficacy of improved stoves in containing deforestation is the response of households. This means that improved stoves must not generate secondary purchases of fuel wood in excess of the reduction of fuel wood consumption achieved by the technical improvement in fuel efficiency. These second order effects are determined by the size of the household demand elasticities and by fuel wood supply elasticity.

Satisfaction of all these conditions implies that improved stoves will reduce deforestation. This is important since interest in this policy has somewhat declined in recent years without any concrete evidence of its failure. Establishing the effectiveness, or otherwise, of improved stoves has important implications for countries involved in efforts to arrest deforestation, as well as for donor nations and development organizations. The results derived from this work are instrumental for the allocation of funds, setting of goals, and expectations attached to stove programs as a complementary policy for forestry management.

A quick review of current policy in the area of forest protection illustrates the appeal of improved stoves. Current measures are typically aimed at demand management and supply expansion. The first encourages the substitution of modern fuels (kerosene, gas, electricity) for traditional fuels (firewood, charcoal, crop residues, dung).[10] Raising fuel wood prices is often advocated to enhance this substitution. Supply augmentation is effected through reforestation, in the form of conventional plantations or agro-forestry practices.[11] Supply expansion also includes improving the efficiency with which wood is produced through the introduction of more efficient charcoal conversion methods.

Conversion to modern fuels is frustrated by the high cost of energy imports, that absorb up to 70% of merchandize exports' revenues in some oil importing countries (Anderson and Fishwick 1984, 4). In fact, this is one of the factors that had initially contributed to the accumulation of foreign debt in most Sub-Saharan African countries.[12] This policy exacerbates balance of payments and foreign debt problems. In The Sudan, conversion to modern fuels is estimated to cost $337 million in 1983 oil prices and biomass consumption (Whitney et al 1987, 320, 330).

Accordingly, switching to modern fuels is hardly a

[10] In the literature, the term "commercial fuels" is used to denote fossil fuels and hydropower. This is misleading since traditional or biomass fuels are also traded through market channels. The term "modern fuels" is used here as a more accurate reference to non-biomass energy.

[11] Agro-forestry is land use practices that combine forestry and food production or animal husbandry in the same form of spacial or temporal arrangement (Lundgren 1985).

[12] The World Bank concluded that "the 1979-80 oil-price increase has produced unsustainable trade deficits for oil-importing developing countries." (World Bank 1981, 42). Oil prices have declined considerably since then, but the deficits have had lasting effects.

viable alternative for reducing dependence on fuel wood and hence slowing deforestation. Indeed, the implicit assumption that biomass will eventually be replaced by fossil fuel energy as a result of economic growth has been behind the reluctance of policy makers in poor countries to develop biomass and other renewable energy sources. Besides, as far as global warming is concerned, conversion to modern fuels is largely irrelevant since the end result is the same: emission of greenhouse gases.[13]

The alternative of raising fuel wood prices is irrelevant for the majority of firewood users since only a small percentage of firewood is produced for the market. Most of it is gathered by households for their own use. This policy is more relevant to charcoal consumers and urban dwellers in general, but its effectiveness is limited by the size of the price elasticity of demand for fuel wood. A low elasticity will depress the response of consumers to any measures involving prices.

In principle, reforestation appears to be relatively simple, but the size of the replanting effort required discourages most sincere officials. In 1983, it was estimated that 50 million hectares of trees will need to be planted in less developed countries by the year 2000 to bring the projected demand and supply levels in balance. At

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[13] This statement may be qualified by calculation of net releases from each source to find out how much each contributes to total emissions. At the present time carbon emissions from biomass in Sub-Saharan Africa greatly exceed those from fossil fuels [Chapter 4, Table 4.11].

the time, this represented a five fold increase in the rate of planting around the world, and fifteen times the rate of planting in Africa (World Bank 1983, 47). With the exception of China, reforestation efforts in less developed countries are extremely modest.[14] In Africa, the area reforested annually is estimated at 9.3% of the total area deforested every year (WRI 1990-91, 292).

Competition for land with food production frequently does not allow devotion of extensive areas of land to plantation purposes. Plantations also have high infrastructure requirements. Labor costs reach almost half of their total expenses. The difficulty and costliness of protection against encroachment by people and animals is another discouraging factor. As a result, fuel wood produced from plantations is rarely competitive.[15]

Agro-forestry relies on work provided by farmers and their families. This can greatly mitigate labor costs, especially where there is underemployment or where the work is a by-product of another task. Agro-forestry also places lower demands on land since trees are spaced between crops, which is also ecologically beneficial. Moreover, it reduces

[14] The extent of reforestation in China between 1980 and 1985 is estimated at 4.55 million hectares a year. This accounts for over 80% of all annual reforestation in Asia, excluding Japan (WRI 1990-91, 293). Other successful planting efforts can be cited in South Korea, the province of Gujarat in India, and the Philippines (World Bank 1983, 48).

[15] FRIDA (1980, 54) estimated the cost of firewood from forestry plantations in the African Sahel at $40-46/m^3$. The average price of firewood in the region then was $30/m^3$. Anderson and Fishwick (1984, 41) estimated the cost of plantation firewood at $71/m^3$ exclusive of transportation and marketing costs, at a 10% discount rate.

soil erosion by simultaneously improving the nutrient cycle and moisture retention. As a result, agro-forestry has a lower per unit cost than plantations.[16] The main difficulty facing this strategy is persuading farmers to undertake the practice.

The lack of willingness to grow trees for fuel in the midst of apparent fuel wood scarcity reflects in part the nature of forests as common property resources. Incentives are classically hampered by the presence of external effects. Since the consequences are not borne by any one individual, the private marginal cost of deforestation is lower than its private marginal benefit. Conversion to private property does not necessarily correct the problem.[17]

This leaves the option of improving the efficiency of charcoal conversion. Charcoal is an important household fuel in Sub-Saharan Africa, especially in urban areas, due to its higher energy content relative to other biomass

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16 It is estimated that in Nigeria the cost of agro-forestry per m^3 is only 7% that of plantations (Anderson and Fishwick 1984, 41).

17 Larson and Bromley (1990) have shown that resources are not necessarily more likely to be degraded under common property regimes than under private property. Private decisions are not always optimal since the externality exists, and privatization does not solve problems of technological interdependence. In addition, the failure to enforce private property rights moots this option. Examples of non-optimality of private decisions are common. In Kenya, privatization of communal forest resources led poor cultivators into marginal lands, and hence intensified soil erosion problems (DEVERS 1979). Assurance of property is another incidence where the optimality of private decisions fails. In Indonesia, loggers have no stake in the reproductive ability of timber forests due to the short length of their leases (Repetto 1990). In the Middle East, oil companies often maximized current production from fear of nationalization.

fuels, and convenience in transportation and handling.[18] However, charcoal use is more damaging to forests because it requires clear-cutting of trees, whereas firewood is most often obtained by collecting dead twigs and branches.

The conversion rate at which charcoal is currently produced from wood is low. The traditional earthmound kiln recovers 15% based on the weight of the dry wood used (Mukhtar 1978, 5; Emrich 1985, 21).[19] It is estimated that adoption of more advanced kilns for production of all charcoal in The Sudan would save about 34% of annually deforested lands, or 11,460 km^2 (Whitney et al 1987, 333). Efforts in this area are hampered by large capital and skilled labor requirements.[20]

In comparison to the above alternatives, the costs of improved stove projects are modest, mainly due to the

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[18] Generally, charcoal has a net heating value of 28.9 Gj/Mt. Oven-dried wood, i.e., that containing zero moisture, has 16.9 Gj/Mt. Agricultural crops like bagasse have an average heating value of 15.8 Gj/Mt (Bogach 1985, 12). The distance at which charcoal becomes profitable to transport compared to firewood has been estimated at 82 km by Earl (1975, 74). DEVERS (1979, 64) estimated it at 80 km for East Africa. This distance signifies the point where the cost of production and transportation of charcoal is equivalent to the production and transportation cost of firewood. Within 80 km radius firewood is cheaper for users than charcoal.

[19] Charcoal conversion efficiency can be defined in either one of two terms. The first one is in terms of weight, where the weight of charcoal output is divided by the weight of wood input, usually expressed in kilograms. The other criterion for measuring charcoal conversion efficiency is energy content, using the same equation as in weight terms (Emrich 1985). The wight measure is more commonly used, even though it is considered less precise than the energy content measure. The latter depends on wood moisture content: a piece of information not as readily available as the wood weight.

[20] The capital cost of the Missouri kiln, which has a conversion efficiency of 25%, was estimated at approximately $2300.00 in 1982 (Whitney et al 1987, 333). In comparison, traditional kilns have zero or little investment cost, and require no maintenance. Brick kilns are very efficient and cost less than metal, portable ones. For instance, the Brazilian bee-hive brick kiln achieves a conversion rate of 47.6%. Its construction cost is about $15/m^3. The Argentinean half-orange kiln achieves 28% conversion efficiency, with a capital cost of $558, and operating expenses of $4.14/ton of charcoal (Emrich 1985, 77,98). In addition to relatively high costs, advanced kilns require large amounts of wood to operate efficiently, and thicker vegetation per piece of land in order to keep transportation costs within reasonable ranges.

absence of infrastructure requirements. In Kenya, it is estimated that a stove that raises fuel efficiency by 20% is more cost-effective than increasing supply through improved charcoal conversion, peri-urban plantations, or subsidizing the use of kerosene (Joseph 1989, 55). The cost-effectiveness of improved stoves has also been demonstrated in West Africa. In 1984, the cost of saving 1 kg of wood in Niger was estimated at 4 cents. The retail price of fuel wood at the time was 5-6 cents per kg (Masse 1985, 27).[21] The cost-effectiveness of improved stoves is also enhanced by their being multi-objective.

From a public policy perspective, improved stoves are attractive because they are based on microeconomic, household level decision making and personal initiative. In contrast, alternative measures such as reforestation hinge on macroeconomic planning and considerable government involvement. Improved stoves stand a better chance at success because they remove decision making from the volatile center of the political process. This is extremely important in the context of Sub-Saharan Africa where political instability is rampant.

The following section reviews previous work on improved stoves, which in part provided the motivation for

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[21] In 1983, USAID estimated the cost of production of 1 m^3 of wood on a plantation in West Africa at 5,000-10,000 CFAF. Communaute Francaise Africaine Franc (CFAF) is the local currency in Francophone West Africa; the exchange rate at the time was $1.00 = CFAF 417.38 (IMF 1983). In Senegal, the cost of an improved stove built by users is estimated at 4,965 CFAF, compared to 9,983 CFAF for those built by masons. The value of the resulting savings in wood consumption are equal to 10,000 to 20,000 CFAF per annum (Gueye and Madon 1983, 640).

this one. Section 3 discusses the research problem. Section 4 explains the methodology used in this study. Results from the present work are discussed in the final section together with policy implications.

2. Previous Work

Previous studies of improved stoves have concentrated on design (VITA/ITDG 1980, Dutt 1978c, De Lepeleire et al 1981), dissemination (Joseph 1989), and social acceptability (Shaller 1981, Agarwal 1983). Recently authors began to address the environmental effects of stoves, mainly in the area of indoor pollution (Smith 1985, 1989, 1993). Analysis of the relation of improved stoves and fuel wood consumption to global warming is still at an early stage.

The relation of improved stoves to deforestation in the literature is somewhat controversial. On the one hand, there is a widely held view that they are not likely to have a significant impact on deforestation since this condition arises from agricultural expansion rather than from fuel wood consumption (Foley and Moss 1983, Foley et al 1984). On the other hand, almost invariably, improved stoves are recommended as essential components of forestry programs on the basis of evidence linking fuel wood consumption, especially charcoal, to forest depletion. In Africa, the effect of concentrated consumption of charcoal is manifested in widening circles around major towns, such as Khartoum and Ouagadougou (Eckholm 1975, Digernes 1977, Floor 1977).

The first view is more relevant to moist tropical forests, particularly in South America, where agriculture is responsible for large scale forest removal (Mahar 1989; Myers, 1980, 1990). Research on tropical deforestation is disproportionately focused on this region. The second view is more applicable to dry savanna lands where fuel wood consumption is the leading cause of land degradation (Myers 1984). Evidence on the two views is examined in Chapter 4.

Studies dealing with the "economic" aspects of improved stoves generally focus on issues pertaining to costs, returns to investment, and production strategy (Agarwal 1986, Hyman 1986). Only two attempts have been made thus far at relating improved stoves to fuel wood consumption, and in turn to deforestation on the basis of economic theory. In the first study, an aggregate input-output model is used to evaluate policy aimed at reducing fuel wood consumption in The Sudan (Murck et al 1985). According to this study, the effectiveness of such a policy is greatly reduced as a result of households' reallocation of income savings generated by improved stoves toward energy intensive goods.

Jones (1988) acknowledged the role of household demand elasticities in reallocation of savings from improved stoves. Using a partial equilibrium model, he evaluated the impact of a hypothetical stove program on fuel wood consumption. Evaluation was based on "parameter values typical of low-income developing countries." His findings indicated that such a program would lose 60% of the technical fuel savings due to increased consumption of fuel wood by households (Ibid., 262). Almost half of that loss is due to fuel wood consumption induced by increases in real income. The remainder is contributed by price effects.

The previous studies treat deforestation as the terminal point of the analysis. Causality flows from policy to fuel wood consumption, to forest depletion. Feedbacks from deforestation to policy measures, in particular the impact of forest depletion on fuel wood prices, are not considered. As argued in the present study, upward pressure on fuel wood prices caused in part by the progress of forest depletion may counteract downward price adjustments to improved stoves, and hence price effects may not be realized. This issue is fully explored in Chapter 4.

The above studies are also characterized by highly restrictive assumptions and extensive data requirements that can be a real obstacle in less developed countries. In the first study, the ability of an aggregate input-output model to capture microeconomic household responses to improved stoves is questionable. The second study is of limited use to African countries. Simultaneous solution of prices and quantities based on the assumption of perfectly competitive markets does not very well approximate the socio-economic profile of Sub-Saharan Africa. Moreover, the number of coefficients required for solution is too large for the model to be of use at an empirical level, given data limitations in the area of traditional fuels.

Accordingly, there is great need for analysis of specific improved stove programs using the analytical framework appropriate to economic structures and data availability. This is not to overemphasize the latter, but as Chapter 2 shows, the data base for analyzing traditional fuels in Sub-Saharan Africa is quite limited. There is an equally great need for examining the environmental effects of improved stoves. The following section outlines the scope and nature of the research problem of this study.

3. The Research Problem

As noted above, improved stoves are evaluated in this study on the basis of three fundamental criteria. These are: the relation between consumption of fuel wood and forest depletion; the ability of improved stoves to achieve substantial fuel savings and deep penetration among fuel wood users; and finally, the parameters determining fuel wood demand and supply. Emphasis here is placed on the third factor since it is the one least explored in the literature.

As stated earlier, assertions have been made that the efficacy of improved stoves as a policy to combat deforestation is threatened by secondary purchases of fuel wood. This premise is examined in the present study and empirical measurement of the actual amount of fuel thus sacrificed is undertaken. In that sense, the present work is policy oriented. Theoretical matters discussed here are largely established in the literature. In the author's judgement, there is greater need for this type of contribution in Sub-Saharan Africa than for theoretical inquiries.

Having said that, the household response to improved stoves is analyzed along the following lines. The change in fuel consumption caused by improved stoves has typically been measured as the outcome of multiplying the change in efficiency times the number of improved stoves in use (El Sayed and Amin 1981, Westwood 1987). This procedure yields only the first order result of improved stoves. But the long term impact on fuel wood consumption depends on the household's behavioral response to improved stoves. Lower fuel requirements due to efficiency improvement will generate real income savings. Reallocation of these savings toward more purchases of fuel may dampen the effectiveness of improved stoves.

Moreover, downward price adjustment in response to the initial reduction in fuel consumption will, <u>ceteris</u>

paribus, trigger further increases in quantities demanded. The magnitude of these movements is determined by income and price elasticities of household demand for fuel wood. The larger these are, the higher will be the secondary increases in fuel wood consumption. Secondary effects are also determined by the fuel wood supply elasticity underlying the price adjustment mechanism. In cases where second order effects are sufficiently large, the policy of improved stoves may be self-defeating.

It is argued here that the second order effects of improved stoves are not likely to be large because the fuel wood market is generally characterized by low elasticities. Low income elasticity is reflected in that traditional fuels are usually replaced by modern fuels as income rises. In fact, the literature review shows that fuel wood income elasticity is negative in many cases, especially in urban areas. Price elasticity is expected to be lower than unity as a result of the lack of close substitutes. Supply elasticity is low due to the presence of various rigidities in the fuel wood market.

Low fuel wood elasticities limit quantity adjustment to changes in market conditions. As a result, the burden of market adjustment falls on fuel wood prices. This means that receding of forest areas may be represented by price hikes more than by changes in the quantities of fuel wood exchanged in the market. If this is true, then downward price adjustments to improved stoves may be swamped, and hence, the price effect may be weakened.

The quantitative results derived from this analysis are relevant as long as fuel wood is purchased. In areas where it is gathered at no monetary cost, the conceptual framework remains valid, but labor time replaces monetary units as a numeraire. Reallocation of freed time will determine how the overall consumption of fuel wood is affected. Households may maintain the same level of fuel consumption to cook extra meals or improve energy-using services in general. In that event, energy efficiency and dietary standards may improve as a result of the introduction of improved stoves, but the rate of deforestation may not.

4. The Research Method

The hypothesis is tested by examination of the experience of improved stove programs in less developed countries, in addition to theoretical and empirical analyses of improved stoves. Theoretical analysis deals with the relation of improved stoves to fuel wood consumption and forest depletion. The framework for analyzing this issue is laid out in Chapter 4. The fuel wood market in relation to forest resources and adjustment mechanisms by producers and consumers, as well as the relation of deforestation to fuel wood prices is examined.

Both the first and second order effects of improved stoves are analyzed.

This is followed by empirical estimation of fuel wood demand and supply parameters in The Sudan, where annual deforestation is estimated at 504,000 hectares (FAO 1986, 82; WRI 1990-91, 292). The Sudan Renewable Energy Project is the major USAID effort in Sub-Saharan Africa involving the introduction of improved stoves (Jones et al 1989). Analysis is focused on the household sector since it uses over 90% of all fuel wood, but implications for other sectors are addressed (SNEA 1987, 42).

The empirical analysis involves econometric estimation of a standard partial equilibrium model consisting of two equations for the capital city of Khartoum. Time series data for the period 1960-1990 are used. The first equation in the model represents household demand for fuel wood. It is used to derive price and income elasticities that determine the response of the household to fuel savings resulting from improved stoves. The second equation, fuel wood supply, yields the size of the price adjustment to reduction in fuel wood consumption.

These elasticities are then used together with data on stove efficiency, household budget shares, and prices of fuel wood to measure the second order effects of improved stoves on household demand for fuel wood in the city. This provides a simplified algorithm for deriving these secondary effects. To expand the scope of the results, demand for fuel wood is estimated for other regions in The Sudan, as well as a cross section of Sub-Saharan African countries. The results are used to arrive at conclusions regarding the efficacy of improved stoves in containing deforestation in the region. Implications for global climate change are examined.

This methodology is predicated on simplicity and minimization of data requirements. As stated earlier, shortage of reliable data imposes severe constraints on analyzing less developed countries, especially in Sub-Saharan Africa. Current literature does not address this issue, but the larger the number of variables or parameters, and the more intricate the models, the higher is likely to be the margin of error in the results. Hence, studies of the type discussed above produce results to which little confidence can be attached.

The method developed in this study is useful for examining the comparative effectiveness of improved stoves on an inter- or intra-country basis. Improved stoves are best located in countries where parameters in the fuel wood market ensure small feedbacks and secondary fuel purchases. On an intra-country level, situations of non-optimal distribution of stoves between urban and rural areas may be identified.

5. Results and Policy Implications

The results derived here are consistent with the hypothesis that improved stoves are in fact effective in slowing deforestation in Sub-Saharan Africa. All the conditions mentioned earlier in this chapter, and which support this hypothesis, are fulfilled. First, the connection between fuel wood consumption and forest depletion exists, although it is more prominent in urban areas and where charcoal use is predominant. Second, there is strong evidence of substantial improvement in fuel burning efficiency, as well as wide acceptance of improved stoves. There are difficulties in these areas. However, these stem from administrative factors rather than from improved stoves themselves.

Finally, second order effects from improved stoves are substantially smaller than the initial reduction in fuel consumption. On the basis of the parameters estimated here, secondary purchases of fuel wood induced by improved stoves reduce the effectiveness of this policy in cutting fuel wood consumption by 42%. Secondary increases in consumption of fuel wood caused by income effects are relatively small. The bulk of secondary purchases is induced by price adjustments, mainly caused by low elasticity of fuel wood supply. Simulation results indicate a sizable potential for secondary fuel purchases, but in no case do improved stoves result in a net increase in fuel wood consumption. In other words, improved stoves work.

In consistence with the literature, the results indicate that elasticities in the fuel wood market are relatively low. Both income and price elasticities, as well as the supply elasticity, are less than one. The results show that household consumption of fuel wood in The Sudan, and by extension Sub-Saharan Africa, varies directly with income and indirectly with fuel wood prices. Elasticity estimates for Sub-Saharan Africa are remarkably similar to those for The Sudan. Insofar as the parameters estimated here are representative, the results can be generalized over other countries in the region.

The results reflect that price does not seem to be as strong a determinant of demand for fuel wood as income. In some cases, this variable is not significant at all. As a result, price elasticity for Sub-Saharan Africa as a region is not quoted. This is in part due to the small sample size. As the literature review illustrates, price elasticity for traditional fuels has not been estimated for any country in Sub-Saharan Africa up to now. This issue is fully developed in Chapter 6.

The results are quite close to those obtained by previous authors for The Sudan, which showed that the effectiveness of an improved stove program is reduced by 48% (Murck et al 1985, 1231). Hence, the procedure used here does in fact provide an alternative to more complicated algorithms involving a large number of parameters that may not be available. The demand parameters generated in the study are useful for general analysis of the energy sector in The Sudan and the region as a whole.

The most important policy implication from the present findings is that improved stove programs are to be promoted as a cost-effective measure to reduce forest depletion in Sub-Saharan Africa. Accordingly, developed countries are encouraged to increase their involvement in this strategy. In general, present funding for improved stoves is limited in comparison with reforestation programs.[22] Improved stoves are likely to be more effective in urban areas. This is consistent with recent findings (FAO 1991).

Improved stoves can mitigate deforestation and serve several social objectives. Thus, they represent an integral part of any comprehensive forestry management strategy. Lowering fuel wood consumption can considerably reduce the size of the reforestation effort required. Improved stoves may also help smooth out the transition to modern fuels if that path is selected, by inducing marginal fuel wood consumers to move up the fuel ladder. In the long run reforestation is the sustainable option, but stoves may be

[22] The share of USAID in the stove component of the Kenya Renewable Energy Project is $160,000, representing only 3% of total funding for the program. Expenditure on agro-forestry ($4.13 million), absorbs 86% of total funding. The remaining 11% are allocated to energy planning and conservation (Jones et al 1989, 117).

instrumental in reducing short term costs, or in providing a remedy until large scale reforestation can be undertaken.

Situations where improved stoves are not effective in slowing deforestation do not automatically dismiss this policy as an element of a development strategy. Arresting deforestation is only one aspect - albeit a major one - of improved stove programs. The general philosophy behind them is to raise income and improve the overall quality of life. Naturally, there are benefits from traditional cooking methods such as space heat, lighting, and protection from wild animals that improved stoves may not replace. These may have to be taken as amenities lost as a result of technological change.

The dissertation consists of seven chapters. Chapter 2 critically reviews the literature on traditional fuels and improved stoves in relation to the phenomenon of forest depletion. Chapter 3 explains the methodology of research and data issues. In Chapter 4 the question of fuel wood consumption and its relation to deforestation is discussed. Chapter 5 analyzes the experience of improved stove programs. Here the dimensions of fuel efficiency, dissemination, and social and institutional constraints are analyzed. Results are presented in Chapter 6. Conclusions and policy remarks are summarized in Chapter 7. All data, detailed results, and conversion factors used are presented in the Appendix.

CHAPTER 2

REVIEW OF THE LITERATURE

Three bodies of literature are reviewed in this chapter. The first is the literature on traditional fuels and fuel wood scarcity, popularly known as the "other energy crisis" (Eckholm 1975). This topic is fully dealt with in Chapter 4. The literature on improved stoves is also treated. Emphasis is placed on studies examining the impact of the policy of improved stoves on the demand for fuel wood, and its relation to deforestation. Also, the demand for energy, with emphasis on biomass fuels, is reviewed since the present work involves estimation of demand for traditional fuels. The purpose of this review is to establish the standard procedure for estimation of energy demand, and to survey results of previous studies.

1. Traditional Fuels

The general approach to energy in less developed countries is characterized by descriptive summary analysis of consumption and price trends, and energy balances to determine the gap between supply and demand.[1] Consumption surveys are occasionally undertaken. But most studies assess aggregate consumption rather than estimate demand in a microeconomic sense (Allen 1985, Cecelski et al 1979). The World Bank energy sector assessment series falls under that category (World Bank 1983, 1986). These surveys are meant to produce broad projections for financing Bank projects. As such, they do not generate useful parameters, such as elasticities, that add much insight in the analysis of household consumption patterns.

The literature on traditional fuels as a legitimate area of energy research came through the back door. Traditional fuels were long neglected because they mostly fell outside the monetary economy (Arnold and Jongma 1977). But discussion of deforestation and associated fuel wood scarcity in the mid 1970s drew attention to the fact that biomass resources provided energy for the majority of the world population, and hence, there was a need for research in that area (Earl 1975; Eckholm 1975, 1976; Digernes 1977; Floor 1977; Club du Sahel 1978; Cecelski et al 1979; Openshaw 1974, 1980). These studies have attained the place of classics in traditional fuels literature.

This is interesting because work on traditional fuels

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[1] Examples of this approach can be found in World Bank (1980), Newcombe (1975, 1979), Dutt (1978), Dunkerley et al (1981a), Hoffman and Mors (1981), Munasinghe and Schramm (1983), Hoffman (1984), The Beijer Institute (1984), McGranahan and Taylor (1977), McGranahan et al (1979), and Schipper et al (1984).

has subsided in recent years. That can be observed in that most statistics in the present work are relatively old. Interest in wood fuels in the 1970s has not changed the convention of reporting only data for modern fuels in official statistical reports. The Food and Agriculture Organization of the UN (FAO) regularly publishes data on prices and production of fuel wood in different countries. However, many data points are missing, making it hard to obtain information for an uninterrupted number of years. Moreover, recent data on consumption of wood fuels are not available anywhere.

By the end of the 1970s, it was widely recognized that traditional fuels represented an extremely important component of the energy sector in less developed countries. Nevertheless, inadequacy of data presented an obstacle to serious research endeavors. Most studies were characterized by pleas for political action and dramatization with little analysis (Eckholm 1975, Floor 1977). Still, there were serious efforts at investigating the problem.[2] These earlier attempts were also characterized by over-emphasis on rural areas (Digernes 1977, Ernst 1977, Fleuret and Fleuret 1978, DEVERS 1979, Wionszeck 1982). Reforestation emerged as the single policy recommendation.

The above approach has come under considerable fire in

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[2] USAID was especially active in this area (DEVERS 1979, USAID 1981). The comprehensive inventory of data on traditional fuels prepared for USAID by Knowland and Ulinski (1979) is one example.

recent years (Leach 1988, Munslow et al 1988, Dewees 1989). These authors contend that the fuel wood problem exists mostly in the minds of aid agencies and development experts, and that fuel wood scarcity must be defined according to priorities as perceived by local populations. That, they claim, is the reason why intervention measures such as forestry plantations, and improved stoves have failed. Leach (1988) attacks what is known as the "gap" approach that the World Bank follows in assessment of fuel wood balances.[3]

This method is based on comparison of aggregate current consumption, population growth rates, and total forest area (Anderson and Fishwick 1984). It relies heavily on official records of forest areas; thereby ignoring community resources such as village lots, farm plantations, and scattered trees. Consequently, the size of the fuel wood deficit is frequently exaggerated (Foley 1987, Leach 1988).

At the same time, this approach can result in overlooking situations of real scarcity. Munslow et al (1988) point out that aggregate demand/supply analysis masks the specificity of each situation. Evidence from Southern Africa shows that pockets of fuel wood scarcity very often exist within well endowed regions. These

[3] This approach has also been used by other researchers in the field of forestry and energy programs. The Beijer Institute of Sweden employed it for evaluation of the energy sector in Kenya (Beijer Institute 1984).

generally go unaddressed under this regime because they mostly lie outside forestry belts. The authors underline that regarding fuel wood consumption, woody biomass is the critical resource.

Moreover, in this approach demand for fuel wood is projected as a linear function of population growth. As a result, forests and tree stocks are projected to decline at an accelerated rate. Thus by setting production rates against population growth and current consumption figures, the conclusion was inevitably reached that consumption exceeded supply by phenomenal margins. Although this is contradicted by some authors. Cline-Cole et al (1990) point out that continuous demographic alterations distort this hypothesis.

The grim forecasts that by the year 2000 all Africa's forests will have been cut down drew considerable attention in the last two decades, particularly with the evidence of escalating desertification in the region (Anderson and Fishwick 1984, Anderson 1986). But the inability of aid organizations to raise interest among local inhabitants in tree growing led some to conclude that the Sahel energy problem had been exaggerated (Noronha 1981, Foley 1987). This "Sahel paradox" solidified dissatisfaction with the conventional wisdom.

At the heart of the criticism is the fact that there has been very little surveying of any kind of affected areas. Moreover, the few surveys that had been undertaken were fraught with discrepancies. In Mali, for instance, only one survey had been undertaken, and it had a two-fold discrepancy. Foley (1987) maintains that expansion of agriculture produces a surplus of wood for fuel, hence there is no fuel wood scarcity. He claims that local wood resources are enough to last Mali well into the next century.

Moreover, real prices of fuel wood in the Sahel have remained constant since 1980, implying that there is no scarcity (Ibid.). But such signals are not as sharp in Sub-Saharan Africa as is held in theory due to the primitive nature of the market structure. Relative prices are probably more indicative of supply trends. Besides, constant prices do not necessarily imply abundance. In Kenya, charcoal prices remained low because of improvements in transportation. Thus, the use of fuel wood prices as the sole indicator of supply/demand movements of forest resources themselves can be misleading.

The need for distinction between physical and economic fuel wood scarcity was stressed by Dewees (1989). Emphasis on physical production obscures other equally important issues. According to him, this emphasis has so far resulted only in a rash of unsuccessful reforestation projects. This position is supported by Leach (1988), who argues that supply/demand calculations of the kind described above are misleading because they fail to allow for market response to scarcity. Consumers respond to fuel wood scarcity in a number of ways such as reducing consumption and changing labor use patterns.

He suggests that if there was a real scarcity, people would not be using as much wood as they are today. This draws on earlier evidence by DEVERS (1979) and Arnold (1979), that fuel wood consumption declined directly with the degree of scarcity in the area. It was observed that where there was abundance of wood resources, per capita fuel wood consumption was considerably higher than in areas of scarcity; and that people used it more efficiently in the latter case.[4] This has led some authors to suggest that the only feasible option is to abstain from any course of action and let depletion escalate to the point where prices will streamline inefficient consumption patterns (Elkan 1986).

The idea that current consumption levels are too high for fuel wood to be scarce is somewhat arbitrary. How much fuel wood consumption is too much for wood to be scarce? Dewees invokes that people deal with scarcity by shared cooking, use of other fuels, and even migration. This is also hazardous to assume. For instance, shared cooking in

[4] Openshaw (1980) found that fuel wood was usually consumed to the point where all wood resources in a particular area were exhausted. Recent evidence from Southern Africa shows that as fuel wood becomes more scarce, people do not move down the fuel ladder, i.e., resort to agricultural crops and dung. Instead, they tend to economize on the use of fuel wood (Munslow et al 1988).

many places is a matter of tradition and cultural practice. Though it might have come about as a result of previous scarcities in the area.[5]

Dewees almost goes to the extent of arguing that the only admissible evidence of wood scarcity is reduced consumption of fuel wood. Other evidence may indicate totally different phenomena such as labor scarcity, and so forth. He adds that the shift to lower grade fuels like crop residues does not always indicate fuelwood scarcity. These may be used for their abundance: trees may sometimes be preserved for other uses such as growing fruits. In Burkina Faso, millet stalks are very popular; they are used more frequently than wood because they are abundantly available after the harvest, they weigh less than wood, and need no stocking (Ernst 1977). However, such evidence may confirm fuel wood scarcity more than otherwise.

The emphasis on fuel wood in rural areas was based on the assumption that the problem of energy in urban areas would be solved by economic growth. Replacement of traditional fuels by modern energy was inevitable (World Bank 1980, 1983). Studies of traditional fuels in the urban areas of less developed countries gained considerable momentum only recently. Attention was drawn to this area after the transition to modern fuels was forestalled by

[5] In The Sudan, this is a common tradition. In particular, young wives are expected to share the hearth with the mother-in-law.

increasing costs of energy imports.[6] Demand for energy in urban areas raises a number of important and interesting issues such as the degree of inter-fuel substitution between modern and traditional fuels within the household (Hughes-Cromwick 1985, Sathaye and Meyers 1985, Munslow et al 1988).

2. Energy Demand Studies

The functional form mostly used for estimation of demand is the double logarithmic form used in this work. Energy demand is expressed as a function of energy prices, consumer income, consumption habits, and population. The logarithmic functional form is extensively utilized in the energy demand literature, mainly because it allows ready derivation of elasticities from the estimated model (Nordhaus 1975a, Pindyck 1979).

Most scholarly work with regard to energy is concerned with the situation in developed countries. It is therefore largely devoted to fossil fuels. Studies proliferated in the second half of the 1970s, reflecting concern with higher oil prices (Nordhaus 1975a, Berndt and Watkins 1977, Danielson 1977, Houthakker and Kennedy 1979). Analysis of demand elasticities occupied a prominent place in these

[6] Use of modern energy in urban areas of Sub-Saharan Africa has either declined or at best remained constant. As a cooking fuel, kerosene suffered the most drastic cuts. In The Sudan, imports of kerosene fell by 68% between 1973 and 1983 (SNEA 1987, 51, 54). In Malawi, kerosene use declined by 24% in the three years following the oil price increase of 1973 (DEVERS 1979, 9). The trend is similar in other African countries.

studies. Interest in demand for energy in less developed countries is relatively recent. Being an extension of the approach in the developed world, studies in this area are focused on modern fuels and industrial demand. There was legitimate concern with the implications of increasing energy costs on economic growth in these countries.

The relation of energy consumption to total output was investigated at length (Desai 1978, Siddayao 1982). There was considerable interest in establishing whether this relation was unidirectional or otherwise. Looking at data for developed countries, Kraft and Kraft (1978) ascertained that causation did in fact flow from Gross National Product (GNP) to energy. This meant that growth in GNP affected energy consumption. But this issue had by no means been settled. It was contested by Akarca and Long (1980). Siddayo (1982) argued that this relationship was not an adequate indicator of energy demand in any way. In fact, the very concept of energy demand elasticity as basis for forecasts is still being questioned (Ramain 1986).

Analyzing the relationship between energy and Gross Domestic Product (GDP) for 47 less developed countries between 1970-76, Zilberfarb and Adams (1981) found that the energy/GDP coefficient was greater than that for developed countries, reflecting a closer energy/GDP relation. In addition, they found that the coefficient was relatively stable, indicating that the energy shock of 1973-4 had little impact on the basic relation between energy use and the level or growth of GDP. Previous studies had suggested that energy intensity rose with economic growth, but Desai (1978) showed that when traditional fuels were accounted for, the ratio of energy use to output actually declined as countries grew.[7]

Most energy studies tend to be highly aggregated. This is true across fuels, sectors, and countries. Pourgerami and Hirschhausen (1991) modeled aggregate demand for energy in Bangladesh, India, and Pakistan. They analyzed the dynamics of demand elasticities in these countries and tested their stability. Their findings indicated that both income and price elasticities were consistently below unity. The absence of data on traditional fuels did not represent an obstacle. They were simply ignored on the basis of the argument that the rapid transition to modern fuels that was taking place made the exclusion of traditional fuels inconsequential.

Wolf et al (1981) estimated demand for oil and other modern fuels in 77 non-oil less developed countries in order to forecast future demand. Their findings showed that income elasticity of demand for oil was extremely low in the short run. The situation changed dramatically in the long run, with elasticity reaching 1.71 (Ibid., 22). The

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[7] Darmstadter (1971) estimated output elasticities of modern fuels for less developed countries at 1.7, compared to less than one for developed countries. Strout (1976) found that energy/output elasticity was 1.3 for both groups of countries. His study included firewood.

same applied to price elasticity. Results of estimation of demand for energy in Organization of Petroleum Exporting Countries (OPEC) member countries undertaken by Al-Janabi (1979, 90) indicated relatively high income elasticity (1.97). A similar study for non-OPEC countries was undertaken by Choe (1978). His study also did not include traditional fuels.

Demand for coal, oil, and natural gas was estimated by Al Sahlawi and Boyd (1987) for a large number of less developed countries in order to assess the effect of oil supply shocks on their energy prices, consumption, and policy. Demand for all fuels was found to be highly price elastic. Cross price elasticities were high, indicating good substitution possibilities. The increase in price in the event of a supply cut due to actions of oil-exporting countries would be substantial. Consequently, they encouraged less developed countries to expand investment in substitute sources of energy.[8]

The aggregate approach in energy demand analysis was criticized as simplistic, inaccurate, and may be inapplicable. Pachauri (1983) pointed out that conventional methods of analysis often broke down when applied to traditional fuels because demand and supply are not always

[8] Their findings showed that demand for oil in Africa exhibited a negative relation with income, i.e., oil was an inferior fuel. This, they explained in terms of countries' desire to diversify their energy portfolios as incomes grew by moving to natural gas. This result was most probably shaped by energy sector characteristics of North African countries, which have a much higher level of fossil fuel energy consumption than Sub-Saharan Africa.

separable. In rural areas households are both consumers and producers of fuel wood. Their objective is to maximize production for private consumption. Thus, shortage of fuel wood represents a time constraint. Pachauri concluded that this "urban-rural divide" has grown larger in recent years because of higher prices of modern fuels. He also argued that emphasis on energy in poor countries resulted in neglect of the broader spectrum of development problems.

Despite the predominance of the aggregate approach, demand for energy has been estimated for certain sectors and fuels.[9] The sectors that received most attention are industry (Khaled 1981, Pitt 1985a), and to a lesser extent agriculture (Bhatia 1984, Parikh and Kromer 1985), and transportation (Noll 1982). Household demand for energy in less developed countries has been largely overlooked, though interest has generally risen in recent years (Leach 1988).

2.1 Demand for Traditional Fuels

Studies of demand for traditional fuels are scarce. This is partly due to the paucity of data, but also because of the assumption that the role of these fuels is

[9] Apart from oil and gas, electricity received considerable attention. Glapke and Fazzolare (1985) estimated residential and industrial demand for electricity in six countries in West Africa. Their findings indicated that price elasticity was higher in industry than in the household sector, while the contrary was true for income elasticity. Overall, elasticity estimates were not considerably different from those for developed countries. Berndt and Samaniego (1983) estimated electricity demand in Mexico to distinguish between access and consumption. Demand for electricity was also examined in Korea (Uri 1983), and Indonesia (Amarullah 1984), in addition to a large number of other countries and regions. See Munasinghe, 1985, and Bhatia, 1987.

diminishing. As will become evident from this review, data is either of poor quality or does not exist. Almost invariably the real variables are replaced by proxies. Accordingly, results need to be taken cautiously. Studies have mostly focused on Asia, particularly India (Pachauri 1980, Alam et al 1983, Macauley 1989, Dunkerley et al 1990). Demand as such has been estimated only for households. Manufacturing and services sectors have not yet been addressed to any extent despite their rising share of consumption.

Generally, studies of demand for traditional fuels have centered around whether these fuels were inferior. Leach (1987, 1988) estimated income elasticities for biomass fuels in rural areas of South Asia between 1977 and 1982. Results for different countries were remarkably close. Elasticities were uniformly low, but did not indicate that fuel wood was inferior. Elasticities varied from 0.32 to 0.51 for Sri Lanka, India, Pakistan, and Bangladesh (Leach 1988, 53).

Pachauri (1983, 223) estimated household demand elasticities in India for both modern and traditional fuels. He found price elasticities to be -0.93 in urban areas and -1.15 in rural areas. Respective income elasticities were 0.92 and 0.76. This implies that an increase in income will have a greater impact on demand for energy in urban than in rural areas. On the other hand, household demand is more responsive to price in rural than in urban areas. Parameter estimates derived through combining modern and traditional fuels must be interpreted carefully. The big difference in consumption patterns and energy contents of the two renders these coefficients meaningless.

Dunkerley et al (1990) examined consumption of cooking fuels - fuel wood, soft coke, kerosene, LPG - by households in the Indian cities of Hyderabad and Raipur.[10] Income elasticity with respect to total household cooking fuels in Hyderabad was -0.05. The same elasticity adjusted for energy efficiencies of different fuels is 0.26; this is an almost entirely different parameter, reflecting the inferior nature of traditional fuels (Ibid., 95). In fact, the estimated income elasticity of firewood consumption was -0.70. The income elasticity of total expenditures on energy was positive since moving up to modern fuels entails larger outlays.

In a widely cited study, Alam et al (1983) estimated demand for fuel wood in the city of Hyderabad, India. The study found firewood to be an inferior good with an income elasticity of -0.80 (Dunkerley et al 1990). That was higher than in rural areas. Kerosene reflected an interrupted

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[10] Liquified petroleum gas (LPG) is a derivative of crude oil, obtained in the refining process together with other petroleum products. It is a mixture of propane and butane gases. In less developed countries, it is used for cooking in households and other establishments such as restaurants and hospitals. LPG can be centrally distributed, but it is more commonly supplied in cylinders of different capacities. In The Sudan, the most commonly used are 12.5 kg cylinders.

pattern where consumption increased rapidly at first, then was substituted with LPG or electricity. LPG had an income elasticity of unity, meaning that its consumption increased proportionately with income.

Pitt (1985a, 209, 212) estimated household demand for all fuels in Indonesia using an expenditure function. He derived cross price elasticities to show that the kerosene subsidy, as a measure against deforestation, was not justified due to the lack of substitution between kerosene and biomass fuels. Kerosene was used mostly for lighting. Therefore, it did not offer much of a substitute to cooking fuels. He did find the cross price elasticity between kerosene and traditional fuels to be relatively small (0.04-0.81). He also found firewood and kerosene to be substantially price elastic for all population groups. Expenditure elasticities for kerosene, charcoal and firewood were 0.45, 0.96, and -0.17 respectively. Thus, firewood is an inferior fuel.[11]

The most commonly cited study of the demand for traditional fuels involved estimation of demand for an array of countries of varying degrees of reliance on traditional fuels. Fernandez (1980, 69-70) estimated income elasticities of household's demand for both traditional and modern fuels in India, Korea, Malaysia,

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[11] Other estimates of energy demand in Indonesia include Strout (1978), Summers (1979), and Gillis (1980). See Pitt, 1985a.

Pakistan, Brazil, Guatemala, Mexico, and The Sudan. Her results showed that income elasticity for all fuels combined ranged between 0.60 and 0.80. Thus generally, household demand for traditional fuels is not highly income elastic.

Fernandez' results showed that in urban areas demand for modern fuels was much more elastic than that for traditional fuels. Electricity and gas had a high income elasticity.[12] As incomes rose, these fuels were substituted for traditional fuels. Traditional fuels were found to be inferior in urban areas of India. For the rest of the countries, income elasticity of traditional fuels ranged between 0.26 and 0.55. These results are remarkably close to those reported by Leach (1987) for South Asia. For modern fuels the range was between 0.36 and 1.18. Income data was used for India and Brazil. For the remaining countries only indirect evidence was available. Hence income was approximated by expenditure data in the case of Korea, Pakistan, and The Sudan, and appliance ownership was used for Mexico and Guatemala.

The study did not include a price variable, also for lack of data. That may bias the income elasticity estimate upwards if income and price are highly correlated. The absence of price data is less problematic in cross

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[12] Elasticities for electricity should be taken cautiously because most studies do not distinguish between electricity end-use for lighting and for cooking. Total electricity consumption is usually the variable used.

sectional analysis because it is usually safe to assume that all consumers face the same set of prices, hence expenditure can be used as a proxy for income in a similar fashion to Fernandez'. This, however, can lead to erroneous results. If prices differ by region or neighborhood, for example, expenditures may not approximate income well.

Another problem commonly faced when estimating demand for energy in less developed countries is the prevalence of supply bottlenecks. Consumption is influenced by availability of fuels (Bhatia 1987, Leach 1988). Some authors would venture to say that if supplies were adequate to meet demand, income elasticity would be higher (Sathaye and Meyers 1985). Supply bottlenecks arise from two factors. The first is shortage of foreign exchange and balance of payments' difficulties resulting in inability to secure adequate supplies of energy and other imports such as spare parts. Thus available amounts of petroleum or gas are rationed in some manner.[13]

The second type of supply constraints arises from domestic factors such as insufficient capacity for electricity generation due to low rainfall. Rationing is handled through regular outages or load shedding. Shortages in traditional fuels occur from transportation failure, especially in the rainy season. In Sub-Saharan Africa, charcoal, in particular, is constrained by this factor

[13] That also affects thermally generated electricity.

because production is confined to the dry season.

The result is that observed demand behavior reflects these supply constraints rather than effective demand, in the form of budget-constrained preferences. This phenomenon is known as unfulfilled demand. Rationing may result in downwardly biased elasticity estimates. Bhatia (1987) suggested dealing with it through special surveys, and gathering indirect evidence such as the size of black markets, or demand expressed in non-monetary phenomena. In the case of fuel wood demand the rate of deforestation may provide such an indicator. Clearly neither is satisfactory and may actually do more harm than good through reading of non-existing clues and misinterpretation of seemingly related events.[14]

In addition to income and reliability of supplies, the factors that influence both the level and mix of fuels used for cooking are prices and consumer preferences (Dunkerely et al 1990). Leach (1987) found that household size had an important influence on consumption as well.[15] Charcoal consumption per household in Nairobi, Kenya, varied positively with household size (Hughes-Cromwick 1985).

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[14] In this approach the cure may be worse than the disease since obtaining non-monetary data is often even more problematic. Very little evidence of actual studies of this type exist. The Indian Central Electricity Authority attempted estimation of demand for electricity in India using non-market data. See Bhatia, 1987.

[15] Others have arrived at a similar result. On a less rigorous level, Maithani et al (1986) regressed consumption of biomass fuels - including agricultural crops and dung - on a number of socio-economic factors in an Indian village. They found that household consumption varied positively with income and household size, while per capita consumption varied inversely with the latter.

Ramifications of the size of the family with regard to total and per capita fuel wood consumption have also been investigated by Cline-Cole et al (1990).

Studies of demand for energy in Sub-Saharan Africa are extremely scarce, but the results are generally similar to those for other less developed countries, especially South Asia, in the direction of relations and size of elasticities (Davidson 1985). In the area of traditional fuels the scarcity of studies is even more striking. As mentioned earlier, elasticities were estimated for The Sudan (Fernandez 1980). Her results showed that traditional fuels were a normal good, with income elasticity of 0.51 in urban areas and 0.80 in rural areas. For commercial fuels, elasticities were 1.185 and 0.85 respectively.

Estimates of income elasticities of demand for energy in The Sudan, derived by The Sudan Department of Statistics in 1982, showed that elasticity of demand for charcoal and firewood in urban areas was -0.59, and -0.93 respectively. Kerosene was also found to be an inferior good with an elasticity of -1.18. Demand for modern fuels was highly elastic, with elasticity reaching 1.41 for electricity and 2.32 for LPG.[16] Earlier estimates by the Department of

[16] The elasticity figure for LPG appears to be too large. However, substantial increases in expenditure on modern fuels are generally recorded as households move from lower to higher income groups. Household expenditures on LPG in The Sudan rose by 20 times between income groups Ls 300-500 a year and over Ls 500 a year (Fernandez 1980, 35). The official exchange rate for the Sudanese Pound (Ls) in the late 1970s was Ls 1.00 = $2.00 (IMF 1983). Income elasticity for LPG in The Sudan actually fell from 3.84 in 1968 (Whitney et al 1985, 12). As always, data errors cannot be ruled out.

Statistics indicated that traditional fuels were normal goods, with elasticities of 0.25 for charcoal, and 0.39 for firewood (Whitney et al 1985, 12). This may reflect a general rise in real income.[17]

Household demand for energy was estimated for Nairobi, Kenya. The fuels included firewood, charcoal, kerosene, electricity, and LPG. Results with respect to firewood showed that its use was anomalous and could not be explained. This is a common problem. Since most firewood is gathered for own use, its consumption does not respond well to price signals. Results found charcoal to be an inferior good with a low income elasticity of -0.23. Income elasticity for LPG was a mere 0.03.[18] The results for electricity, where the income elasticity was 1.58, indicate high response of electricity demand to income changes (Hughes-Cromwick 1985, 277).

This confirms findings for India that the total amount of cooking fuel per household does not increase substantially with income. Instead, the mix of fuels varies as people move up to modern fuels (Dunkerley et al 1990). The results also reflect the intermediate nature of gas as a cooking fuel. Lower income groups consume charcoal and kerosene for cooking purposes. When income rises, they

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[17] The two sets of estimates are not strictly comparable, however, because of differences in the sets of data (Whitney et al 1985).

[18] This represents a deviation from all the results reviewed so far. Modern fuels typically had considerably high income elasticity.

substitute toward gas, and ultimately electricity. Thus gas either serves as a "luxury" primary cooking fuel supplemented by cheaper charcoal or kerosene, or as a residual cooking fuel supplementing electricity (Hughes-Crommwick 1985). This agrees with the findings of Alam et al (1983). Results of studies of demand for traditional fuels are summarized in Table 2.1 below.

TABLE 2.1

ESTIMATES OF INCOME ELASTICITIES OF
DEMAND FOR ENERGY IN SELECTED COUNTRIES

Country	Date	Firewood	Charcoal	LPG	Electric.
India					
urban[2]	1983	-0.80		1.00	
urban[1]	1963/4	-0.104		0.357	
rural[1]	1963/4	-0.003		0.195	
Pakistan	1971/2				
urban[1]		0.263		1.044	
rural[1]		0.546		0.662	
Sudan					
urban[1]	1967/8	0.507		1.185	
rural[1]	1967/8	0.804		0.849	
urban[3]	1980	-0.93	-0.59	2.32	1.41
Kenya					
urban[4]	1981		-0.23	0.03	1.58

Sources: 1- Fernandez, 1980.
2- Alam et al, 1983.
3- Whitney et al, 1985.
4- Hughes-Cromwick, 1985.

Modern fuels are included in the Table for comparison. The wide difference between elasticity estimates for the two types of fuels is clear. In most cases traditional fuels are inferior. In Sub-Saharan Africa, they are inferior only in urban areas. Absolute income elasticity for charcoal is lower in Kenya than in The Sudan. Income elasticities for electricity are generally higher than those estimated for West Africa, which were 0.63 in Nigeria, 0.28 in the Ivory Coast, and 1.01 in Togo (Glapke and Fazzolare 1985, 143).

The price coefficients in the study on Kenya were statistically insignificant. Thus the author was unable to obtain meaningful results with respect to prices of traditional fuels. Results were only used to indicate the direction of the relation between price and consumption, not the magnitude of that effect. In order to avoid biased income elasticities, the study assumed uniform prices. The same procedure was followed by Fernandez (1980). This problem is frequently encountered when estimating demand for woodfuels in less developed countries. Prices do not seem to influence consumption as much as theory predicts (Barnes 1986, Leach 1988).

This problem can be seen in other studies of demand for traditional fuels in Sub-Saharan Africa. Most are unable to estimate demand rigorously due to lack of data on the price variable. So far it has not been possible to locate a study where price elasticities for traditional fuels have been estimated anywhere in Sub-Saharan Africa. Most studies represent estimation of linear relationships of fuel wood consumption with any number of related socio-economic variables.

Abakah (1990) estimated the effect of income and inflation on consumption of fuelwood in Ghana from 1974 to 1987. His study did not estimate a demand function. Rather, it represented a linear relationship, where the total national consumption of woodfuels was regressed against the national consumer price index and real minimum wages - as a proxy for income. The results indicated the inferior nature of woodfuels. Inflation exerted a positive effect on woodfuels' consumption. That may reflect substitution into these fuels as the cost of living increases.

3. Improved Cookstoves

The volume of literature on improved stoves is impressive. The conventional wisdom is that improved stoves are important and should be encouraged. Improved cookstove programs "constitute one of the most important components of fuel wood demand management and are a necessary complement in...the process of promoting tree-planting for fuel," (Manibog 1984, 225). Nevertheless, the dominant approach focuses on issues of technology and dissemination, vis-a-vis the impact of stoves on fuel wood consumption and deforestation.[19] This may be appreciated in light of the poor understanding of the traditional energy sector.

The environmental effects of improved stoves with regard to toxic emissions from wood burning is a much more recent area of research. "Economic" evaluation of stoves usually discusses financial costs to manufacturers and households, pay back periods, and returns from private investors' perspective (Cecelski 1983, Agarwal 1986, Hyman 1986). Dissemination of improved stoves is a central question since it is the ultimate determinant of their effectiveness. Guidelines for diffusion strategies have been adequately discussed by Clarke (1985), and by Cáceres et al (1989).

Suitability of improved stoves to local life styles and their ability to fulfil the various functions provided by traditional stoves represents a central theme in stoves' literature. Based on data from India, it was concluded that improved stoves were resisted because they entailed financial cost, could not replace traditional methods in areas other than cooking, and interfered with cooking habits and styles (Agarwal 1983).

Studies of specific improved stove programs usually provide critical insights and lessons. For instance, the

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[19] The literature dealing with technical matters such as stove design and fuel efficiency reflects the complexity of the task. See Dutt, 1978c; VITA/ITDG, 1980; De Lepeleire et al, 1981; VITA, 1983; Prasad, 1982, 1985; Agarwal, 1986; and Gill, 1987. Efforts to establish international testing standards have been led by Volunteers in Technical Assistance (VITA), but have not yet produced concrete results. This issue is further elaborated on in Chapter 5.

improved stove program in Kenya showed the importance of involving the private sector in dissemination of stoves (Jones et al 1989). Shaller's evaluation (1981) of the Lorena stove program in Guatemala showed that people accepted and appreciated the stove but not for fuel wood savings. Rather, people were more concerned with reduction of smoke, and cooking time. The various stove programs in West Africa, especially in Senegal, have also been the subject of several studies (Walton et al 1978, Ulinski 1981, Wood 1981, USAID 1981, Gueye and Madon 1983).

The impact of improved stoves on deforestation in the literature is not quite clear. Some authors have argued that improved stoves were not likely to have a major impact in preventing deforestation, though they might bring some benefits to individual households (Foley and Moss 1983). The reason is that deforestation is caused by land clearance for agriculture rather than reliance on biomass energy. Fuel wood is available as a surplus from agricultural operations.

This issue is fully treated in Chapter 4, but a few words are in order in this context. The relative contributions of agriculture and fuel wood consumption to deforestation in Sub-Saharan Africa represent an area of controversy that has not yet been cleared. One of the reasons is that a number of phenomena are swept under the heading of deforestation. As Chapter 4 demonstrates, fuel wood consumption is a much more significant factor than has been believed.

It is common now to state that improved stove programs in rural areas may not be effective in slowing deforestation (FAO 1991). The reason is that people in rural areas do not cut live trees for fuel wood but gather branches and twigs. In other instances they use surplus wood from land cleared for agricultural projects. This, however, is not overwhelmingly the case. Digernes (1977) found that in the rural area of Bara in The Sudan inhabitants did remove young trees when they could not find wood otherwise.

A broad survey carried out in 1987 in several countries for the Intermediate Technology Development Group (ITDG) confirmed the finding that rural consumption of fuel wood may not be damaging to the environment. This was true in all countries with the exception of Kenya.[20] The conclusion of the survey was that "Effective urban programmes that sell large numbers of stoves to low income groups can have a real impact on deforestation;" (Joseph 1989, 56). It is somewhat firmly established now that urban demand for fuel wood, particularly charcoal, is a significant cause of deforestation in Africa. This is reflected in the appearance of desert areas around urban centers (Eckholm 1975, Floor 1977, Anderson and Fishwick

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[20] The survey covered improved stove programs in Kenya, India, and Indonesia.

1984).[21]

Gill (1987) also argued that improved stoves would not be effective in reducing deforestation. But his criticism had to do with the design of improved stoves more than with fuel wood demand patterns. He maintained that many improved stove designs had lower fuel efficiency than traditional stoves because the former were intended to achieve a number of objectives other than reduction in consumption of fuel wood. His approach implies concentration on one objective at a time. However, the dominant view is that improved stoves are a multi-purpose device and that design should accommodate that attribute (Prasad 1985).

Foley et al (1984) conducted the most comprehensive survey of stove programs to date. They concluded that when stove programs are examined within the context of development problems, they may not be justified considering the host of more pressing needs. This may be true depending on the specific benefit-cost ratios obtaining in different countries. As stated earlier, the evidence available up to now indicates the cost-effectiveness of improved stoves compared to other measures of forestry management. This point is further discussed in Chapter 5.

The environmental aspects of stoves have only recently gained some attention. Pioneering work in the area of wood

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[21] Cline-Cole et al (1990) observed a different pattern in the town of Kano, Nigeria, but did not see enough reason to reject the above hypothesis.

smoke has been undertaken in Africa (Smith 1993). Smith (1989) also discussed the impact of stoves on reducing or altering the mix of emissions from fuel wood burning. Even though stoves may reduce overall emissions, they may actually raise emissions of some gases and pollutants as a result of the modification in the combustion process. For instance, improved stoves reduce emissions of carbons but may raise those of sulfur oxides and phosphates (Whitney et al 1987).

Smith also drew attention to the point that in terms of overall indoor pollution, it is not only the level of emissions per stove that is important, but also the time required for cooking which determines the total exposure level. Hence, if a stove reduces emissions only modestly, but significantly cuts cooking time, it may not be necessary to modify design to reduce actual emissions. Moreover, studies take reduction in smoke as evidence of reduced emissions. That is misleading. The two are not identical. For instance, charcoal is smokeless but it emits carbon monoxide that can be extremely hazardous in poorly ventilated units.

One of the important considerations of charcoal versus wood-burning stoves was raised by Hyman (1986). He pointed out that the introduction of charcoal-using stoves may induce substitution of wood or even LPG by charcoal, which is more environmentally damaging than wood.[22] That has been observed in Kenya. During evaluation of the improved stove project there it was observed that some people, attracted by fuel savings, switched from other fuels to charcoal. This has to be measured against total fuel savings as well as the specific source of charcoal to the area where in some instances it is procured from land already cleared for other purposes such as agriculture.

Very few attempts have been made at investigating the effects of improved stove programs on the demand for fuel wood. In the first study of this type (Murck et al 1985, 1231, 1240) an aggregate input-output model was developed in order to simulate the results of a policy for the reduction of wood use in The Sudan. The policy included the introduction of more efficient stoves in urban areas. It was assumed that stoves were adopted by all households. On the basis of their model, an improved stove with 10-20% fuel efficiency improvement would lose about 48% of its effect on fuel wood consumption due to higher expenditures on goods and services that involve the use of wood fuel in their production. Food is probably the most significant example.

The emphasis in the study is on modelling rather than

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[22] As noted above, wood is gathered by rural families for domestic use, and usually consists of twigs and fallen branches. Charcoal is commercially produced for urban consumers. It requires clear-cutting of trees on a wide area of land at a time. This issue is fully dealt with in Chapter 4.

the applicability of the method to the socio-economic structure under examination.[23] This can be seen in that the model involved 9 sectors, 37 commodities, 6 inputs, and 7 demand categories. The data requirements for this model render the results rather suspect. The study used a highly aggregate structure to infer results of decisions undertaken at the household level. Behavioral variables in household' response were not adequately analyzed. A unity income elasticity of demand for all goods was assumed but it was only implicitly featured in the analysis.

Several studies have mentioned that improved stoves may lead to some increase in fuel wood consumption as a result of income effects, though this was not adequately explored (Cecelski 1983, Foley and Moss 1983, Jones et al 1989). Whitney et al (1987) mentioned that stoves would actually raise overall energy consumption by raising income. However, they assumed that people would substitute into modern rather than traditional fuels. Their overall evaluation was that improved stoves were economically and environmentally beneficial especially at lower income levels. On the other hand, Abakah (1990) argued that it would be pointless to introduce improved stoves without simultaneously increasing income.

Jones (1988) was the first to analyze the impact of

[23] The authors state that "the emphasis in this paper, however, is on the application of linear programming and entropy maximizing techniques to derive the intermediate flows in a rectangular input-output table.." (Murck et al 1985, 17).

improved stove programs on households' demand behavior. He suggested that demand elasticities played an important role in the reallocation of savings from improved stoves. His model addressed this aspect both initially and after fuel wood prices had time to adjust. Jones argued that improved stoves would induce secondary purchases of fuel as a result of income effects, i.e., savings from reduced fuel requirements. The reduction in fuel requirements would increase consumption by reducing prices. In addition, purchases of goods and services that require energy in their production might enforce that outcome.[24]

Jones' results showed that a hypothetical stove program would lose 60% of its fuel savings due to the increase in purchases of fuel wood by households. The leakage in fuel savings attributed to the income effect is 25% on average. This jumps to almost 60% when prices are endogenized to the system. Accordingly, the price effect is the dominant factor. The parameters used in Jones' study come from a wide group of countries, mostly in Asia and Latin America. He uses an income elasticity of unity and a price elasticity of 0.50 (Ibid., 256). Supply elasticity used is also one. With the exception of price elasticity, these parameters are too high for Sub-Saharan Africa.

Jones does not offer any explanation for the finding

[24] Jones' study draws attention to other behavioral changes at the household level that may dampen the impact of improved stoves on fuel wood consumption, for example, switching from eating out to cooking at home.

that the price effect is relatively large. It is suggested here that the price effect is the dominant one since quantity adjustments in the fuel wood market are limited due to low elasticities. Moreover, if this turns out to be true, then the progress of deforestation will be reflected in price increases which may swamp the downward price adjustment resulting from improved stoves.[25]

Jones divides households' consumption into four categories: fuel wood, food, traditionally fueled goods, and goods produced with modern fuels. Some goods are produced in both sectors, using traditional and modern energy: examples are bread, bricks, and cement. The choice of fuel in the two sectors is not entirely independent. Shortage of fuel in the modern sector is reflected in expansion of the traditional one. As a result, the elasticities derived may not be good indicators of the true effects of each group of commodities. This is likely to show up in the form of multicollinearity if actual estimation is attempted.

The number of coefficients required by Jones' model is

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[25] One possibility that Jones overlooks is that if fuel wood is an inferior good, improved stove programs will be extremely desirable because as incomes rise, people will substitute out of fuel wood and into modern fuels, although this substitution is limited by the ability of improved stoves to use the various types of fuel. As stated above, the relationship between income and fuel wood consumption was found to be negative in several countries. In that event, the larger the income elasticity, the greater the substitution, and hence, the more effective a stove program is. In this context, Jones' model does not investigate inter-fuel substitution within the household, which largely dictates the implications of a negative income elasticity.

too large to be useful at an empirical level.[26] In light of pervasive dearth of quality data, Jones' model offers little help. This is particularly relevant for elasticities with respect to demand for "traditionally fueled" manufactured goods. Data on traditional industry is extremely limited; certainly not available to estimate demand elasticities. This problem is avoided in the present study by using a simpler procedure to arrive at similar results. Moreover, the simultaneous solution of demand/supply relations undertaken in both of the above studies is not adopted here due to the assumption that fuel wood markets in The Sudan are not perfectly competitive.

Jones' study uses household elasticities for manufactured goods and services to predict the increase in demand for fuel wood by the "traditionally fueled" manufacturing sector. That is not recommended because the firms' supply of those goods is determined by other factors not included in the households' demand function. Separate estimation of the manufacturing sector's demand for fuel wood is likely to yield more reliable results.

Summary and Conclusions

1) The literature on traditional fuels is lacking in

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[26] The required coefficients are household's budget share for charcoal, the cost share of charcoal in manufacturing, income and price elasticities of demand for charcoal, supply elasticity for charcoal, cross elasticity of demand for charcoal, and income elasticity of demand for traditionally-fueled manufactured goods.

many respects. The most important is rigorous analysis of demand behavior, especially in urban areas. There is too great an emphasis on the supply side of the market for traditional fuels. Estimation of price elasticities is rare. For Sub-Saharan Africa it is non-existent. Important contributions were made in 1970s but interest has receded since then. The present work hopes to bridge these gaps by estimating income and price elasticities for The Sudan, as well as demand elasticities for a cross section of other countries in Sub-Saharan Africa. This is used as the basis for analysis of improved stoves in the region.

2) By and large, the literature indicates that household energy use, especially cooking, dominates the energy sector in less developed countries. Household demand for traditional fuels is characterized by low income and price elasticities. Income elasticities appear to be generally higher in Sub-Saharan Africa than in other regions. Firewood is mostly an inferior fuel, especially in urban areas. Modern fuels have a relatively high income elasticity. Elasticities are higher in rural areas for traditional fuels, while the opposite is true for modern fuels. Inter-fuel substitution within the household is driven by income changes more than by price fluctuations.

3) This lack of analysis of demand for traditional fuels has limited the evaluation of improved stoves to areas of design, diffusion, and financial returns. Their

impact on fuel wood demand, and hence deforestation, has not received due attention. Few attempts have been made at analyzing the economic impact of improved stoves at the household or micro levels. The techniques employed in these studies are either based on highly restrictive assumptions, or extensive data requirements. Besides, evaluation is limited to quantitative results, not supplemented by evidence on the pattern of deforestation. The present study suggests that the entire impact of stoves on forest depletion cannot be captured quantitatively.

4) The literature on deforestation is overwhelmingly concentrated on moist tropical forests in South America. Studies on arid and semi-arid areas, especially in Africa are scarce. Moreover, the literature in general is characterized by lumping various phenomena from total destruction of forests to minor land conversion under deforestation. Most authors maintain that land clearance for agriculture is the most significant cause of forest depletion. As the present study shows, the role of fuel wood consumption in deforestation in Sub-Saharan Africa is underestimated.

5) The environmental effects of improved stoves such as reducing harmful emissions that increase indoor pollution or reducing the risk of burns are only recently being investigated. Studies generally indicate that improved stoves can greatly reduce pollutants released

during cooking. The role of the household sector in greenhouse gas emissions in the atmosphere, and potential contribution to global climate change is yet to be addressed.

The following chapter lays out the approach used in the present study to address some of the shortcomings of previous studies, and to measure second order effects of improved stoves on the demand for fuel wood.

CHAPTER 3

RESEARCH METHOD AND DATA

The purpose of this chapter is to present the analytical framework, and discuss the method used in investigation of the research problem and derivation of results. The present study involves theoretical and empirical analysis of the impact of improved stove programs on demand for fuel wood, and the implications for forest depletion. The theoretical analysis is based on a model of the fuel wood market describing the relationship of fuel wood consumption, prices, and deforestation. This model is introduced in Chapter 4. Analysis of the manner in which improved stoves modify the above framework is undertaken in Chapter 5. This part also deals with the social, technical, and environmental issues pertaining to improved stoves.

The empirical analysis entails derivation of the parameters underlying fuel wood supply and demand in order to evaluate the impact of improved stoves on the demand for fuel wood. Parameters are derived through econometric estimation of a static partial equilibrium model consisting of two equations, representing the fuel wood market. The first equation is households' demand for fuel wood. The second one is fuel wood supply. The Sudan is used as a case study. The model is estimated for the capital city of Khartoum. In addition to the model, a number of demand relations are estimated in order to substantiate the results and expand their applicability and generality to Sub-Saharan Africa.

The model attempts to arrive at results similar to those obtained by previous authors using a simpler formulation. The decision to use a simple model is based on desire to economize on data, the lack of which may render the most sophisticated models inoperable. The empirical analysis occupies Chapter 6. The first two sections in this chapter are devoted to discussion of the analytical framework. The final section discusses the nature of data, their sources, and reliability.

1. Theoretical Analysis

The process of deforestation and its relation to fuel wood prices is examined. Analysis of the microeconomic effects of improved stoves at the household level is undertaken. The analysis is cast in terms of a hypothetical stove program. It is focused mainly on the household sector that accounts for over 90% of fuel wood consumption in Sub-Saharan Africa. Implications for other sectors using fuel wood are addressed in relative depth.

The microeconomic effects of improved stoves are discussed along the following lines. The final impact on fuel wood consumption depends on the household's behavioral response to stoves, in addition to the response of fuel wood prices to the reduction in consumption.[1] The crucial effects of improved stoves fall in two parts: income effects and price or substitution effects. At the individual household level the introduction of an improved stove will immediately reduce fuel requirements. The size of that initial reduction is determined by the stove's efficiency improvement. This is an exogenous reduction in fuel requirements due to technological change.

Depending on the price of fuel, the household realizes real income increases. If fuel wood purchases comprise a relatively large item in a household's budget, then the use of an improved stove can raise real income significantly. The pattern of reallocation of this increase is the main determinant of the resulting final reduction in consumption, since some of the extra income may be reallocated to fuel wood purchases. The size of these purchases depends on the income elasticity of demand for fuel wood. Reallocation of real income increases toward more purchases of fuel resembles a leakage in fuel savings

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[1] As Jones (1988) has pointed out, the household response may also include other behavioral variables pertaining to substitution between fuels and cooking or eating habits.

from improved stoves.[2] This is the income effect.

The price effect is realized through downward price adjustment in response to the initial reduction in fuel consumption. That would lead to an increase in quantities of fuel wood demanded by households, as well as other consumers. The magnitude of these increases is determined by the price elasticity of demand. The size of the price drop is determined by supply elasticity. The greater it is, the smaller will be the resulting drop in price due to greater capacity for adjustment. Thus, the introduction of improved stoves places upward pressure on quantities of fuel wood consumed. Similar increases in fuel wood consumption in other sectors will reinforce these results.

As stated in the introduction, the hypothesis to be tested in this study is that improved stoves are effective as a policy to contain deforestation. The situations that may render this hypothesis false are: the absence of a relation between fuel wood consumption and forest depletion; the failure of improved stoves to reduce fuel consumption per stove, or to be accepted by users; and finally, the presence of substantially large second order fuel wood purchases. The first two elements are discussed first. But, the bulk of the analysis focuses on the third

[2] As noted earlier, if fuel wood is an inferior good, this will enhance the impact of improved stoves since income savings will induce substitution of fuel wood by superior fuels; that generally means modern fuels. However, this may be true only if improved stoves use both types of fuel in order to allow that substitution to take place.

one that has to do with elasticities in the fuel wood market.

It is argued here that fuel wood elasticities are uniformly low, i.e., below unity. The relevant elasticities are: own price, income, and supply elasticities. This has two outcomes: 1) smaller quantity adjustments, and hence large price adjustments which, other things remaining equal, will result in large price effects; 2) because quantity adjustments are relatively limited, the progress of deforestation is likely to be reflected in price movements rather than changes in quantities of fuel wood exchanged in the market.

For final analysis of the impact of improved stoves on the scale of forest depletion, two assumptions underly this study. First, aspects of implementation of improved stove programs such as technical design and production strategy have been solved. Second, it is assumed that the rate of stove penetration is 100%. In other words, stoves are successfully disseminated and adopted by all fuel wood users. The economic effects will be weighed against the environmental and social problems improved stoves are expected to mitigate.

2. Empirical Analysis

As mentioned earlier, the empirical analysis is undertaken to provide the parameters required for evaluation of how much improved stoves can reduce fuel wood consumption by households. This section provides some background on the country selected as the case study, and discusses the motivation behind that selection. The following section explains the equations and the estimation technique used.

2.1 The Sudan as a Case Study

The Sudan is the largest country in Africa, with a total area of 2.5 million km^2 (World Bank 1992, 218). About half of this area is desert and semi-desert. Approximately 40% of the remaining area is savanna woodlands (Earl 1984, 15). The country is divided into 7 administrative regions (Figure 3.1). Population is estimated at 25.1 million, mostly concentrated along the Nile in the central plains (World Bank 1992, 218).[3]

The Sudan is one of the countries designated by UN as "Least Developed." Per capita income was estimated at $300.00 in 1985 (World Bank 1987, 202).[4] The economy grew annually by an average of 0.21% between 1965 and 1985.[5] As a result, real per capita income actually fell during that

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[3] Population grew by 3% per year between 1965 and 1980. Current rates have levelled off at 2.8% annually, which is expected to persist until the year 2000. Urban population grew by 4.8% a year from 1980 to 1985 (World Bank 1987, 202, 1991).

[4] The reader will note that most statistical information for The Sudan is relatively old. More recent information for the country is unavailable in World Bank reports or other sources. This is perhaps due to the country's currently unstable political situation.

[5] Average per capita income in Sub-Saharan Africa was $340 in 1989, with an average annual growth rate of 0.3% between 1965 and 1989 (World Bank 1991, 205).

period. The country has been plagued by political unrest represented by a civil war that places great pressure on the central government budget. Life expectancy at birth is 50 years; infant mortality is 104 per 1,000 live births (World Bank 1991, 204, 258).

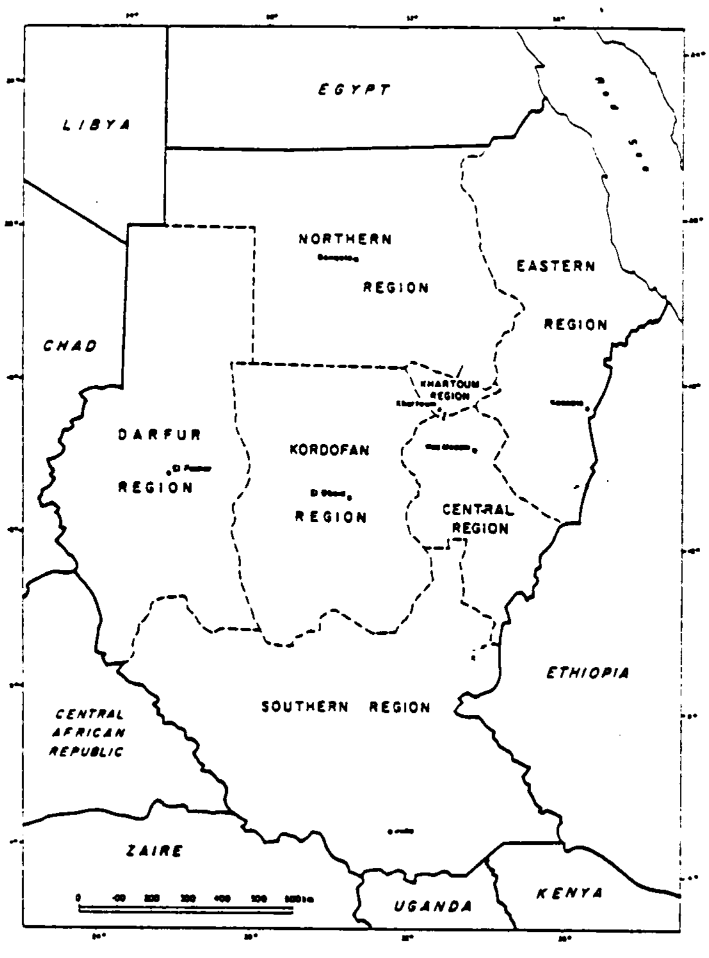

Figure 3.1 Administrative Regions of The Sudan

The Sudan economy is typical of Sub-Saharan Africa. Agriculture contributes 26% of GDP, 94% of total merchandise exports, and employs over 70% of the labor force.[6] Manufacturing represents a mere 9%, while industry as a whole represents 18% of GDP. In recent decades the share of the services sector has grown rapidly, reaching 57% of GDP in 1985 compared to 47% in less developed countries on average (World Bank 1987, 206, 222, 264). This possibly reflects expansion of the informal sector as a result of active rural-urban migration.

The average annual growth rate of the urban population between 1965-85 was 5%, compared to 3.9% in less developed countries (Ibid., 266-7). The majority of those who migrated in recent years are peasant farmers and unskilled workers affected either by drought or by war. Hence, they are most likely to end up in the pool of urban unemployment or engage in informal sector activities.

The principal agricultural exports are cotton, groundnuts, sesame, gum arabic, and sorghum. Agricultural production grew by -5.5% annually between 1980-85, compared to an annual growth rate of 2.9% between 1965-1980. Value added in agriculture declined from $1,754 million in 1970 to $1,511 million in 1985.[7] As a result, imports of cereals

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[6] The share of agriculture in GDP has fallen from 54% in 1965. The average share of agriculture in GDP for low income less developed countries is 32% (World Bank 1987, 206).

[7] This is in 1980 dollars.

increased from 125,000 metric tons in 1974 to 1.1 million in 1985. Food aid received by the country increased by 16 fold in the same period (Ibid., 204, 212).

The country suffers from a large foreign debt and a persistent foreign exchange shortage. The total foreign debt was estimated at $15.4 billion in 1990. In the same year the debt to exports ratio reached 1,829%. In 1980 the debt service to exports ratio was 25.5%. This declined to 5.8% in 1990 as a result of a series of rescheduling efforts. The current account deficit - exclusive of foreign aid - was $1.22 billion in 1990 (World Bank 1992, 252, 258, 264).

The country is coping with the foreign debt by curtailing imports. This is reflected in sluggish performance in all sectors in the economy due to the lack of essential inputs, mainly fuels and spare parts. The result is low capacity utilization, especially in industry. Expectedly, there is no addition to capital. Between 1980-85 gross domestic investment grew by a negative 12.9% annually (World Bank 1987, 208).[8] In effect, the country is using its capital stock to finance current consumption. Average annual inflation rates rose from 11.5% in 1965-80

[8] Between 1965-80 average annual growth in gross domestic investment was 6.4% (World Bank 1987, 208).

to 31.7% during 1980-85 (Ibid., 202).[9] High inflation rates have partially been reflected in fuel wood prices.

The situation with respect to the energy sector is also typical of Sub-Saharan Africa. Modern energy, dominated by petroleum, provides less than 20% of total energy consumption in The Sudan. In 1990, per capita energy consumption was 58 kilograms of oil equivalent (KGOE). This is even lower than the Sub-Saharan African average of 103 KGOE.[10] Per capita energy consumption for The Sudan has declined from 67 KGOE in 1965 due to cut backs made necessary by the sharp increase in oil prices (World Bank 1992, 226-27).

Still, the value of energy imports represented 51% of the total value of merchandise exports in 1985, thereby imposing a heavy burden on the economy. Imports of some fuels, especially kerosene, have been cut severely. The bulk of modern energy is consumed in urban areas. The capital city uses an average of 40% of all petroleum products (SNEA 1991, 63-65).[11] Modern fuels are mostly used in transportation and industry. The household sector uses only 2.5% of petroleum energy (Ibid., 30).

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[9] Inflation rates have risen sharply since the beginning of the 1980s. Repeated devaluation of the Sudanese pound has been undertaken as part of the structural adjustment program prescribed by the International Monetary Fund (IMF). Today the Pound is worth 0.4% of its 1980 dollar value (IMF 1980-1990). It is not clear whether that has had any effect insofar as reducing inflation.

[10] This is very low even compared to less developed countries' average consumption. Per capita consumption for low and middle income countries is 605 KGOE (World Bank 1992, 227).

[11] In 1989, Khartoum province consumed 32% of national gasoil consumption, 60% that of gasoline, and 55% of LPG (SNEA 1991, 63-65).

The principal source of energy is biomass in the form of firewood, charcoal, and to a lesser degree, crop residues.[12] In 1989-90, wood provided 80% of total energy consumption; that amounted to a little over 5 million tons of oil equivalent TOE (Ibid., 59). Per capita consumption is estimated at 2.00 m^3 (Mukhtar 1978, 4). In rural areas per capita consumption is estimated at 1.30 m^3 (Digernes 1977, 77). Consumption of charcoal is particularly prominent compared to other African countries, representing about one third of all energy consumption. Consumption rose by more than 8 fold between 1962 and 1976 (Mukhtar 1978, 5).

The household sector uses over 90% of all biomass, and 75% of all energy used. This is a general feature of Sub-Saharan Africa. Industry and services use 3% and 4% respectively of total biomass energy (SNEA 1991, 51). The main industries using firewood are bakeries (12%), brick making, and tobacco curing. Urban and rural patterns of consumption differ. Firewood is mostly used in rural areas. It is estimated that 95% of the urban population uses charcoal (Jones et al 1989, 95). While charcoal is a predominantly urban fuel, its consumption has been rising faster in rural areas. Household use of electricity and LPG

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[12] Due to the large agricultural sector there is a significant volume of crop residues. The main crop residues used are cotton stalks and groundnut shells. Small amounts of animal waste are also consumed. It is estimated that 11% of crop residues and 8% of animal waste are used for energy (SNEA 1991, 45).

is limited to urban areas.

Environmental problems in The Sudan are numerous but two stand out.[13] The two are deforestation and desertification. It is estimated that the annual deforestation rate between 1980 and 1985 was 504,000 hectares a year of the total forest area (World Bank 1991, 268). Most of this is in open forests, where a total area of 500,000 hectares is annually cleared (FAO 1986, 82). The rate of depletion in closed forests is estimated at 4,000 hectares. Deforestation is attributed to fuel wood use, bush fires, drought spells, overgrazing, shifting cultivation, and mechanized agriculture.

In the Central and Western parts of the country severe desertification has been taking place for the last two decades. The reasons are believed to be low rain fall, excessive exploitation, and wood cutting that exceeds regeneration rates around most villages.[14] Rainfall has witnessed a considerable drop since the mid 1960s, yet it is not clear if this represents a long term condition.

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[13] Environmental problems in The Sudan include water pollution, mainly as a result of household waste disposal, but also because of industrial waste. The costs of water borne diseases in terms of health care and lost work hours has not been accurately assessed, but it is believed to be sizable. Water pollution also occurs due to the improper use of pesticides and other chemicals. Other environmental problems in the country include river pollution, mobile and stationary source air pollution, locust attacks on agricultural crops, and dust storms. For a discussion of environmental problems in The Sudan see Hope and Marie Johnson, 1979; and Kormondy, 1989.

[14] Some authors believe the natural vegetation cover is adequate to supply fuel wood requirements. However, there are pockets of shortage around population centers (Olsson and Rapp 1991). Contrary to widely held opinion, considerable deforestation in rural areas is caused by fuel wood consumption. Digernes (1977) found that in the village of Bara, Central Sudan, villagers cut down live young trees as well as collected branches and twigs.

Over-utilization is reflected in overgrazing caused by the excess of the animal stock in relation to grass resources. It results in shortening of the fallow period from the traditional 14-18 years to 4-5 years (Olsson and Rapp 1991, 194). This has resulted from population growth, reduced yields, and eagerness to expand cash crops area.

The problem of heavy depletion of wood resources is exacerbated by the distribution of forest resources vis-a-vis population concentration areas. The total area of forests in The Sudan was estimated at around 108 million hectares in 1983. Over 70% of forest land is located in the Southern Region, which has only 10% of the country's population (SNEA 1991, 43). Transportation infrastructure is highly undeveloped.[15] As a result, forest resources in the Central part of the country, which is the main source of charcoal used in Khartoum, are being depleted at a rapid rate.

Charcoal production is responsible for most forest destruction in The Sudan, reaching an estimated 3.1 million hectares per annum (Whitney et al 1987, 319).[16] In the

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[15] There is only one line of railroads linking the Northern and the Southern parts of the country. In the rainy season these are inoperable. River transportation is hampered by the vast swamp region in the South. As a result, when available, transportation costs are high.

[16] The reader will notice that this figure is considerably higher than the FAO estimate for total deforestation in The Sudan. Although Whitney's figures do seem to be rather high, they are considered more reliable in analyzing fuel wood-related deforestation than those of FAO for the following reasons. First, FAO estimates are older, reflecting deforestation for the period 1981-85. Second, FAO estimates are likely to underestimate deforestation because they rely on data showing land cleared for agriculture. Moreover, FAO relies on official statistics that overlook considerable unrecorded illegal cutting of wood as will be discussed momentarily. As this section indicates, estimates by Sudanese researchers show that in the beginning of the 1980s, forest destruction attributed to charcoal production to supply Khartoum was already about half the

beginning of the 1980s, an area of about 239,200 hectares was annually cleared for production of charcoal for Khartoum (Muhamed Ali 1984, 27).[17] This shows a marked increase from the 37,440 hectares estimated in the late 1970s (El Sayed and Amin 1981, 97). The city has a population of about 3 million inhabitants (SNEA 1991, 60).[18] In 1990, consumption of fuel wood totalled 275,512 TOE (SNEA 1991, 50). The city produces only 5% of its charcoal requirements (Mukhtar 1982, 7; Muhamed Ali 1984, 27). Households are the primary users of charcoal.

There is some disagreement as to what percentage of charcoal supplies comes from land already cleared for agriculture as opposed to land cleared specifically for charcoal production. Official sources claim that the ratio is 80% of all charcoal consumed in The Sudan (SNEA 1987, 44). But that is debatable because it is based on official data on land licensed for charcoal production. Considerable unlicensed production takes place. The legal charcoal industry is concentrated in the Central Region of the country (Figure 3.1), where the Forests Administration levies a charge on production by licensed charcoal producers.

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estimate of FAO for the whole country (Muhamed Ali 1984). Thus, the probability of underestimation by FAO may not be negligible.

[17] Jones et al (1989, 95) estimated that charcoal production for Khartoum is responsible for the clear-felling of 8,000-15,000 hectares annually.

[18] This could be an underestimation. In recent years drought and civil war have generated an influx of refugees into the city.

The size of the illegal charcoal industry is believed to be comparable to that of legal charcoal production (Mukhtar 1982).[19] It is estimated that the allowable cut set by the Forests Administration covers only 51% of fuel wood consumption, and that less than 1% of charcoal is produced on a sustained yield basis (SNEA 1991, 48). This indicates the existence of considerable illegal wood cutting. Earl (1984, 22) reported that the sites of charcoal production have reached the Ethiopian frontiers, more than 400 kilometers away from Khartoum.[20]

Charcoal production technology in The Sudan is still primitive, using the earth kiln.[21] This method requires little or no capital outlays but it operates at a low charcoal conversion rate; therefore it is considered technically inefficient. The rate of charcoal recovery by this method does not exceed 15% of the air dried wood weight (Mukhtar 1978, 6). At least 20% of the wood remains on site in the form charcoal fines (Earl 1984, 12).

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[19] It is believed that the Sudanese charcoal industry is "well developed in its earth kiln technology and very well organized... and .. is providing a good fuel at reasonable price.. with little or no foreign exchange, and should not be disturbed lightly." (Earl 1984, 12).

[20] Jones et al (1989, 95) estimated that charcoal is being hauled from as far as 800 kilometers away from Khartoum.

[21] Production is carried out during the dry season. The preferred species is Acacia Senegal. Kilns are placed within a radius of 50 meters from the wood source, but wood that lies further is carried to the kiln site. Wood is left to dry for an average of 15 to 30 days before the carbonization process starts. The kiln base is levelled and carefully trodden-in. Pieces of wood are arranged on top of each other in a cone shape, beginning from the large pieces to smaller ones, leaving a tunnel on the side for draught control. The top is then thatched with grass and soil to a depth of 10 cm. The kiln is lit through the tunnel. Carbonization begins at the top of the kiln and progresses downwards. Burning lasts for 5 to 15 days. The kiln is allowed to cool off for about 10 days (Earl 1984, 17-18).

Attempts to utilize these fines have not been successful [Chapter 5].

The charcoal industry is characterized by non-competitive structure. Production is monopolized by a few large producers, frequently representing established families. This is one of the reasons why the model equations in this study are not solved simultaneously. Most producers hire agents to conduct operations of labor recruitment, procurement of water, and organizing transportation of the finished product to marketing centers. Transportation costs amount to 41% of the price of charcoal, while the cost of labor is 27% (SNEA 1987, 45). Agents are paid on commission basis. Charcoal is usually bagged in sacks weighing 30 to 45 kgs and sold in residential areas. In poor areas consumers buy much smaller loads at higher prices. The retail market displays a more competitive structure.

From this review it can be seen that The Sudan is a typical Sub-Saharan African country that displays most of the region's economic and environmental ailments. It fits the thematic framework for this study, namely the tension between economic growth and the environment in poor countries. Severe resource shortage coexists with a host of environmental problems. In terms of the issue at hand, The Sudan has a high level of dependence on fuel wood, and deforestation is acute. The country has a significant improved stoves experience. As stated earlier, USAID has one of its major stove initiatives there.

Moreover, political instability in countries such as The Sudan favors policies in line with the public policy approach embraced here, i.e., decentralization and reliance on individual initiative, and household level decisions. At this point it is very doubtful that The Sudan is able to embark on a large scale reforestation program due to shortage of funds. Present reforestation efforts are very modest. Currently, reforestation covers about 280 hectares a year, or less than 4% of the total area deforested annually (Jones et al 1989, 95). Therefore, improved stoves offer an attractive alternative.

Finally, the same parameters that will set the pace for economic performance in the rest of Sub-Saharan Africa in the near future, namely the foreign debt, agricultural production, and the level and pattern of energy use, are at work here. Availability of data was an important factor in the selection of The Sudan as a case study, but the analysis was not compromised in the process.

2.2 The Model and Auxiliary Equations

As indicated earlier, the model represents fuel wood demand and supply relations in Khartoum, while the auxiliary equations feature demand in The Sudan as a whole, in addition to demand in a number of African countries. The parameters estimated are: household income and price elasticities of demand for fuel wood, and fuel wood supply elasticity. First, the functional form and variables of the equations are discussed, then estimation techniques are reviewed.

All the demand functions to be estimated here are double-logarithmic. As stated in the literature survey, this is the most commonly used functional form in econometric demand analysis, particularly energy (Nordhaus 1975a). It is preferred because it allows direct interpretation of estimated income and price coefficients as elasticity measures (Intriligator 1978). The demand function is:

$$Q_{dt} = A\ P^{\alpha}_{ct}\ P^{\beta}_{gt}\ Y^{\delta}_{t} \qquad (3.1)$$

Q_{dt}, P_{ct}, P_{gt}, and Y_t represent the total quantity of fuel wood consumed by households, fuel wood price, the price of LPG, and household income at time t respectively. The term A is a constant. LPG is included as a substitute for fuel wood in cooking, which is the principal energy-using household activity. Kerosene is used mostly for lighting. Electricity for cooking is used by an extremely small percentage of households. Thus, LPG is the closest substitute to fuel wood.

The equation after taking natural logarithms is:

$$\text{Ln } Q_{dt} = \text{Ln } A + \alpha \text{ Ln } P_{ct} + \beta \text{ Ln } P_{gt} + \delta \text{ Ln } Y_t + \mu \qquad (3.2)$$

The term μ is a stochastic error term to account for omitted variables, mis-specification, and errors of measurement. The own price and income elasticities are α and δ respectively. The expected signs for these elasticities are $\alpha < 0$, and $\delta > 0$. The income coefficient δ can also be negative, indicating that fuel wood is an inferior good.

The parameter β is fuel wood demand elasticity with respect to LPG prices. It is the cross price elasticity between traditional and modern fuels represented here by charcoal and LPG respectively. A positive elasticity indicates that the two are substitutes, whereas a negative parameter indicates complementarity. β is expected to be small, but greater than zero. The large price differential between modern and traditional fuels renders substitution between the two fuels rather limited.

The own price elasticity α is expected to be low, i.e., less than unity, due to the lack of close substitutes. Most urban families have to be completely impoverished before turning to fuels inferior to wood. On the other hand, modern fuels are highly priced, and the cost of appliances to the consumer is a deterrent to most households. As stated in the literature review, price elasticities for traditional fuels have not been estimated previously for Sub-Saharan Africa, and very rarely for other regions. Jones (1988, 256) used a price elasticity of -0.50 on the basis of Pitt's study on Indonesia.

Generally, studies of household energy demand include family size as an independent variable (Hughes-Cromwick 1985, Hyman 1986). This variable is not included in the equations estimated here for lack of data, but that should not pose a problem for two reasons. First, the variable is not believed to have a major impact in determining consumption; its effect is likely to be marginal. Second, family size mostly affects per capita consumption, whereas the variable estimated here is aggregate household consumption.[22] At any rate, the implications of family size for fuel wood consumption are examined in Chapter 5.

Attempts were made to incorporate consumption habits in the demand equation by estimating a dynamic model. In households, decisions are likely to be greatly influenced by habit formation and past decisions. However, the inclusion of a lagged quantity variable led to serious estimation problems. Shortage of data precluded options to deal with those problems. As a result, the model estimated here is static.

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[22] See Chapter 2, section 2.1.

The supply equation to be estimated is:

$$\text{Ln } Q_{st} = \text{Ln } D + \phi \text{ Ln } P_{ct} + \mu \qquad (3.3)$$

where P is still the price of fuel wood. Q_s is the quantity of fuel wood supplied. The coefficient D is a constant. The coefficient ϕ represents supply elasticity. It is expected to be relatively small but > 0. The underlying supply constraints are fully discussed in Chapter 6. One example of supply constraints is the shortage of fuel for transportation of wood to marketing centers. Also in the rainy season fuel wood supply is highly inelastic due to transportation difficulties and limitations of charcoal production technology.[23]

The income effect, which is the percentage change in fuel wood demand induced by income savings from improved stoves (dC_i), involves two elements: the increase in real income realized from lower fuel requirements, and the household's response to that increase. The first element is obtained by multiplication of the percentage exogenous reduction in fuel use (dC), i.e., the technical stove efficiency improvement, times the share of fuel wood in the household's budget (s). The resulting change in household demand for fuel wood is the outcome of the first element

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[23] The supply equation is also estimated with transportation cost as an independent variable to ensure that the function is identified, since transportation is not a shift variable in the fuel wood demand function. See Pindyck and Rubinfeld, 1981.

multiplied by the income elasticity of demand δ. This is summarized in equation 3.4.[24]

$$dC_i = \delta \; s \; dC \qquad (3.4)$$

The budget share of fuel wood in Khartoum is rather low compared to some African countries. Eckholm (1975, 6) reported that fuel wood purchases absorbed a quarter of families' income in Niger. The Sudan Department of Statistics (1982, 67) estimated that in the late 1970s fuel wood expenditures represented slightly less than 5% of total household expenditures in Khartoum. By 1989, this share increased to 10% (Jones et al 1989, 95). The more recent figure is used in this study since fuel wood prices have risen rapidly since 1980. In fact, prices almost tripled between 1987 and 1990. Income did not keep pace with that increase.

The price effect (dC_p) involves price adjustment to the reduction in fuel wood consumption by improved stoves, and the household' response to the price adjustment. The price adjustment (dP) is determined by the exogenous reduction in fuel consumption (dC) and the logarithm of supply elasticity (log ϕ). This is then multiplied by the price elasticity of household demand α to obtain the total price effect. The logarithm is used since the size of supply

[24] Equation (3.4) is adopted from Jones (1988).

elasticity exerts an inverse effect on price movements. Hence, the total price effect is:

$$dC_p = \alpha \log \phi \, dC \qquad (3.5)$$

The term dC_p represents the percentage change in fuel wood purchases as a result of a drop in its price. The total leakage due to both the income and price effects (TdC) is therefore equal to $(\delta s + \alpha \log \phi)$ dC. This formulation using the logarithm of the supply elasticity is a short cut, or a simple way of obtaining the price effect to avoid too many demands on data. The alternative solution of these relations requires further information on other aspects of the fuel wood market, which is not available in most cases.[25] The robustness of this formulation will be examined by comparing the results to those derived by previous authors.

The two model equations are independent of one another, i.e., they are not estimated as a system. This means that simultaneous solution of prices and quantities is not undertaken. Simultaneous solution of the type that Jones used for analysis of improved stoves is not considered appropriate for this study because it requires a more sophisticated market structure than the one observed

[25] The reader is referred to Chapter 2, where the literature survey shows that alternative derivations of similar results were arrived at using more complicated formulations.

in fuel wood markets in Sub-Saharan Africa. Most firewood is consumed entirely outside market channels. Charcoal markets are characterized by a few large producers who have monopoly over transportation and marketing.

In addition to the model, several demand relations were estimated in order to substantiate the results and double-check their reliability. The reason for this procedure is the relative scarcity of estimates of demand elasticities in Sub-Saharan Africa. All attempts at estimating demand for traditional fuels in the region represent estimation of Engel's curves, i.e., estimates of the relation between consumption and income. Estimates of price elasticities are unavailable.

The auxiliary relations estimated here are: aggregate household demand for fuel wood in The Sudan, household demand for fuel wood in a cross section of regions in The Sudan, demand for fuel wood in two groups of African countries, and demand for fuel wood in Burkina Faso. The Sudan demand function, which covers the same time period as the model equations, is:

$$\ln Q_{dt} = \ln A + \alpha \ln P_{ct} + \delta \ln Y_t + \mu \qquad (3.6)$$

where Q_d is aggregate household fuel wood consumption in the country, P_c is average price of fuel wood in the country, and Y is income, represented by GDP. LPG is not included because its use is limited to urban areas; it is not expected to be an important factor on a national level.

The equation for regional household demand for fuel wood does not include an income variable due to the unavailability of data. Thus, the equation is:

$$\text{Ln } Q_{dt} = \text{Ln } A + \alpha \text{ Ln } P_{ct} + \mu \qquad (3.7)$$

The absence of income should not bias the results because income and price are not likely to be highly correlated. The two non-model equations are not used in any calculations. They are mainly used as indicators of the direction of the effect of fuel wood prices on households' consumption of that commodity.

The three equations estimating demand in Sub-Saharan Africa are used to determine the extent of applicability of the model results to the entire region. The first represents a full demand equation in a cross section of eight countries.[26] The second equation represents demand for fuel wood in 20 African countries.[27] This equation does not include a price variable because of lack of data. It is used to indicate income elasticity. In the third equation, demand for charcoal in Burkina Faso is estimated for the

[26] The countries are Burundi, Ghana, Ivory Coast, Kenya, The Sudan, Tanzania, Togo, and Zambia.

[27] In addition to the previous 8 countries, this sample includes Benin, Burkina Faso, Ethiopia, Liberia, Malawi, Mauritania, Nigeria, Rwanda, Senegal, Sierra Leone, Uganda, and Zaire.

period from 1972 to 1980.

Burkina Faso is selected mainly because it is the only country for which enough data is available for estimation of a demand function. The country hosts the headquarters of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS), and the coordinating body of improved stove programs in the region. It has itself been the site of many stove programs. As a country with very limited resources and high desertification rate, Burkina Faso has a considerable stake in the effectiveness of improved stoves. The country has received sizable financial aid for its stove programs. Hence, it is worth investigating its fuel wood demand parameters.

2.3 Estimation Technique

The model is estimated using annual time series data for the period 1960-1990. Overall, one hundred and thirty versions were estimated. These versions included experimentation with variables and with different methods of estimation.[28] The estimation technique finally selected is Ordinary Least Squares (OLS), which yielded the most satisfactory results, particularly in terms of the overall fit of the model. Instrumental variables estimation was attempted in order to correct errors in data measurement.

[28] Results in the Appendix to this document do not include all the model versions estimated. Those that are not reported are available upon request from the author.

Since this technique involves the replacement of original variables by instruments, it was not used due to data limitations.

Tests were performed for the three main econometric problems that affect estimates' accuracy or unbiasedness: serial or auto-correlation, multicollinearity, and heteroscedasticity. Serial correlation is of concern here due to the use of time series data. In particular, the fact that data for the earlier years are estimates gives rise to correlation in the error term. This problem does not affect coefficients' unbiasedness and consistency, but it renders confidence intervals and hypotheses testing results inaccurate (Intriligator 1978). All equations were corrected for serial correlation. The procedure used for correction is Yule-Walker. This procedure is generally preferred because it utilizes all data observations.[29]

Multicollinearity, signifies correlation between the independent variables, may also arise here due to the use of multiple regression analysis. This problem renders parameter estimates inaccurate, and in severe cases results in failure of estimation altogether. The present analysis is particularly sensitive to it because the coefficients estimated are used in calculation of the income and price effects of improved stoves. Accordingly, multicollinearity

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[29] The alternative procedure, Cochrane-Orcutt, typically results in loss of the first observation in the data set (Pindyck and Rubinfeld 1981).

was measured for all equations.

There is no known way of eliminating multicollinearity other than dropping some of the explanatory variables. Unfortunately, this option is available only if its use does not drastically reduce the overall significance of the estimated model. The option was exercised in the case of LPG, as will be explained momentarily. The model versions where multicollinearity was relatively high were excluded from calculations.

Heteroscedasticity exists where the assumption of constant variances is violated. This problem affects error variances such that OLS estimation does not generate minimum variances (Pindyck and Rubinfeld 1981). Heteroscedasticity normally arises in cross-section rather than time series analysis, but the exceptionally wide range in the data points in the present case may lead to violation of the assumption of constant variances. This is reflected in the difference between prices of charcoal and also income at the beginning and the end of the estimation period. The Goldfeld-Quandt test performed indicated no presence of heteroscedasticity.

As stated earlier, numerous versions of the model were run. The final demand equation selected for evaluation of improved stoves depicts household demand for charcoal as a function of charcoal price and household income. The reasons are elaborated below. The first model equation estimated included LPG prices [Equation 3.2]. This generated poor results.[30] The model has a good overall fit. The F tests are relatively large and significant. Adjusted R^2 indicates that the model explains over 80% of the variation in the data. However, each price coefficient (fuel wood and LPG) is not highly significant, especially after correction for serial correlation. This is due to a serious case of multicollinearity.

Fuel wood and LPG prices seem to be highly correlated. Also, the LPG coefficient shows a negative sign, indicating that LPG is a complementary fuel to fuel wood rather than a substitute. The perverse sign does not pose a great problem since the coefficient is not significant, but its implications are investigated in Chapter 6 in light of comments by previous authors of the complementary nature of the relation of LPG to other cooking fuels.

Accordingly, LPG was removed as an explanatory variable from the model equation. This is supported by two factors. First, the cost differential between LPG and fuel wood, in terms of price and appliance cost, is such that they may not be viable substitutes at most income levels.[31] The percentage of households that use LPG in Khartoum is extremely small. As a result, the price of LPG should not

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[30] For results see Appendix A-8 and A-9. The implications of these results are discussed in Chapter 6.

[31] This issue is discussed more fully in Chapter 5.

be expected to influence consumption of fuel wood to a significant degree. Second, LPG prices are regulated by the government, and rarely change to reflect market trends or scarcity cost to consumers.

Estimation of the equation without LPG improved the overall significance of the model. This confirms that LPG is not a critical variable, and hence its elimination should not greatly affect the results. Thus, the final demand function estimated is:

$$\mathbf{Ln}\ Q_{dt} = \mathbf{Ln}\ A + \alpha\ \mathbf{Ln}\ P_{ct} + \delta\ \mathbf{Ln}\ Y_t + \mu \qquad (3.8)$$

The second task was to select the appropriate proxy for the consumption variable. In this vein, the model was first estimated in terms of fuel wood, where the quantity consumed combined both firewood and charcoal. In this version, the overall model for Khartoum is significant at all levels. All variables show their expected signs, i.e., fuel wood consumption varies directly with income and indirectly with price. Adjusted R^2 is 0.81. However, there is a serious case of multicollinearity. After correction for serial correlation, the price coefficient became totally insignificant, with a standard error amounting to 56% of the estimate.[32] These results may be explained in

[32] Results are reported for both Khartoum and The Sudan in Appendix A-12, A-13. Results for The Sudan are very poor, though R^2 indicates that the model explains over 50% of variation in the data.

the following way.

A considerable number of consumers collect firewood rather than purchase it. These consumers are included in fuel wood consumption data generated by surveys, which is the data used in this study. This is bound to reduce the observed influence of prices on quantities of fuel wood consumed. In 1976-77, only 9.7% of total firewood used in The Sudan was produced commercially; the remainder was gathered by consumers for their own use (Mukhtar 1978, 6). Most likely, the ratio of fuel wood produced commercially is higher in urban areas, but firewood provides a small percent of urban energy anyway.[33]

To circumvent this problem, separate demand equations for charcoal and firewood were estimated. Since charcoal is entirely produced commercially, consumption decisions should respond to price signals. The alternative would have been to exclude the percentage of firewood collected from total fuel wood consumption. But this is hazardous since the uniformity and stability of firewood consumers' response to price signals is not guaranteed. When firewood was estimated separately, price was not significant in determining firewood consumption by households: an expected

[33] As mentioned in the literature review, historically authors have had problems estimating a full demand equation for traditional fuels in Sub-Saharan Africa, partly due to this aspect of the fuel wood market (Fernandez 1980, Hughes-Cromwick 1985, Abakah 1990).

result. Income is significant only at the 5% level.[34]

Estimation of a separate equation for charcoal considerably improved the results, as will be fully discussed in Chapter 6. Accordingly, the final model estimated is based on households' demand for charcoal in Khartoum. This assumes increased importance due to the fact that the majority of improved stoves introduced in The Sudan are designed to burn charcoal. Moreover, households' consumption of charcoal represents an even larger share of total consumption than does households' consumption of firewood. Charcoal consumption is more concentrated in the household sector than firewood. Industry does not consume any charcoal.[35] This helps focus the extent of the stoves impact on fuel wood demand.

Thus, the demand function used to evaluate improved stoves in Khartoum depicts households' consumption of charcoal as a function of charcoal prices and households' income. The supply equation shows quantities of charcoal supplied in Khartoum as a function of charcoal prices. No particular problems were encountered in estimation of the fuel wood supply function.

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[34] The results for household demand for firewood in Khartoum indicate that the model explains 63% of data variation. The F statistic is low (26.99), but significant at all levels. Multicollinearity is extremely high, therefore parameter estimates may be highly inaccurate. Interestingly, firewood price has a negative sign that persists even after correction for serial correlation. For details see Appendix A-14.

[35] Very small amounts of charcoal are used in the services sector, mainly in small traditional restaurants and coffee houses.

3. The Data

As mentioned earlier, one of the important features of this study is minimization of unnecessary demands on data, by using as little of it as the analysis permits. Models that emphasize structure risk inoperability. This study arrives at similar results as previous studies using a simpler model and fewer data points. The importance of this consideration can be appreciated given the absence of recent information on traditional fuels in general.

Sources of data for the empirical analysis are fuel wood consumption and price surveys undertaken periodically by The Sudan National Energy Administration (SNEA). Data from the Forests National Corporation (FNC) is not used due to lack of consistency. Fuel wood prices are retail prices in Khartoum as published by The Sudan Ministry of Energy and by FAO. When discrepancies between the two arose, the FAO prices were used. Data for the other African countries is also obtained from the FAO series on forest products.

Total nominal GDP in Khartoum is used as a proxy for household income. The latter could not be obtained. Estimation of the model with real income raised multicollinearity sharply, thus, nominal income is used. Income data is obtained from the Annual Economic Survey issued by The Sudan Department of Statistics, and from the International Financial Statistics published by the IMF. The two track each other very well. Household budget share

data is based on the Expenditure and Income Survey published by the Department of Statistics.

Some of the data points with respect to income were extrapolated on the basis of previous information and the author's judgement. Price data are highly reliable, though fuel wood consumption figures for early years are estimates by SNEA staff rather than results of surveys. Generally, the data is of relatively good quality, being subject to the usual limitations of measurement errors found in normal samples.

Information on improved stoves in The Sudan is provided by a number of official bodies. First, the Sudan Energy Research Council (SERC) is where most of the improved stoves introduced are designed. The second is the FNC, that has itself introduced a number of stoves. Third, the National Stove Network coordinates work between all parties involved in improved stoves' development and commercialization. These include government agencies, research institutes, and aid agencies. Finally, the SNEA is the part of the Ministry of Energy concerned with national energy planning and oversight. A voluminous body of literature can be found on improved stoves.[36]

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[36] In 1988, the regional workshop on the commercialization of improved stoves in East Africa took place in Khartoum; and produced a number of useful documents that summarized the experience of improved stoves in the region (SERC 1988).

Summary and Conclusions

1) This chapter has reviewed the research method used in this study. The hypothesis is tested using both theoretical and empirical analysis. The effect of improved stoves on demand for fuel wood, and so on deforestation is examined within a framework of the fuel wood market introduced in Chapter 4. It is argued that quantity adjustments in the fuel wood market are rather limited, thereby placing the burden of adjustment on fuel wood prices. This is so because both demand and supply elasticities in the fuel wood market are relatively low. This has the implication of modest second order purchases of fuel wood by households in response to savings induced by improved stoves.

2) Empirical estimation of demand and supply parameters in the fuel wood market in The Sudan is undertaken to test this hypothesis. A procedure for calculation of second order effects from improved stoves is proposed here as an alternative to complicated formulations that place too much demand on data that is not always available in poor countries. The empirical analysis based on The Sudan is generalized to Sub-Saharan Africa through a number of supplementary equations and other indicators. The basis for the analysis of improved stoves is established in Chapter 5, while results of empirical analysis are discussed in Chapter 6.

CHAPTER 4

BIOMASS ENERGY AND DEFORESTATION

As stated earlier, deforestation has serious consequences. This chapter examines the dimensions of this condition, particularly in relation to fuel wood consumption. It establishes the basis for determining how improved stoves may produce an impact on forest depletion through modification of the economic parameters underlying that process. Special emphasis is placed on the situation in Sub-Saharan Africa.

The chapter is divided into three sections. The first deals with biomass and its role in the energy profiles of poor countries. The analysis focuses on fuel wood as distinguished from other biomass fuels since it represents the bulk of this energy source. The second section is a broad survey of the status, causes, and consequences of tropical deforestation. The relation between deforestation and fuel wood prices is analyzed in this section. The final section investigates the relation of fuel wood consumption to the phenomenon of global warming.

1. Biomass

1.1 Biomass in Less Developed Countries

Two billion people, representing over 70% of the population of less developed countries, rely on biomass for energy. Over 80% of all wood harvested in these countries is used for energy, compared to less than 20% in the developed world (WRI 1985, 5). Wood provides around 50% of total energy in poor countries. This ratio reaches 80% in Africa (Arnold and Jongma 1977, 3). In rural areas biomass is almost the only source of energy available. Firewood represents about 75% of total biomass energy. The remainder is supplied by charcoal, crop residues, and animal dung.[1]

In 1971, total consumption of fuel wood in less developed countries was estimated at 1.20 billion m^3 (Ibid., 2). The real figure is thought to be probably greater by a magnitude of three because of inadequacy of statistics, and problems associated with measurement of wood fuels in general. By 1976, the total consumption of fuel wood in less developed countries reached 2.46 billion m^3 (Openshaw 1980, 73). Average annual per capita consumption was estimated at 1.5 m^3, varying from 0.17 m^3 in Lebanon to 2.3 m^3 in Tanzania. Households accounted for over 90% of per capita consumption in some instances (Arnold and Jongma 1977, 3; Openshaw 1980, 74).

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[1] Openshaw (1980) believes the true figure for charcoal is probably twice as high.

Table 4.1 indicates that 57% of all fuel wood was consumed in Asia and the Pacific, 23% in Africa, and 19% in Latin America. However, per capita consumption was highest in Africa, followed by Latin America, and finally Asia. Wood provided 75% of energy in Sub-Saharan Africa, 30% in Asia, and 20% in Latin America. In the latter, fuel wood is mostly used in industry, but household consumption is greater in mountainous areas, e.g., the Andean range, where heating requirements are relatively high.

TABLE 4.1

CONSUMPTION OF FUEL WOOD IN LESS DEVELOPED COUNTRIES, 1971

Region	Total Mn m^3	Per Capita m^3	% of total Energy
South-East Asia	278	0.91	62
South Asia	267	0.38	43
China and Others	148	0.18	9
Total Asia	693		29
North Africa	55	0.50	41
West Africa	110	0.92	75
East Africa	117	1.14	75
Total Africa	282		66
Central America	33	0.36	9
South America	199	1.03	29
Total Latin America	232		20

Source: Arnold and Jongma, 1977.

As fuel, firewood is dominant in rural areas, and at lower income levels. As income rises, and people move to urban areas, firewood is replaced by charcoal. On the basis of per capita consumption, the ratio of firewood to total fuel wood used within households in rural areas is estimated at 76% compared to 32% in cities (Openshaw 1980, 74). Charcoal use is greater in Africa compared to other areas. In regions of severe deforestation the use of crop residues and animal dung is more significant, but as a rule, these fuels are more prominent in Asia. Crop residues represent over 60% to 67% of traditional fuels in Bangladesh, China, and Taiwan. Dung represents about 25% of biomass fuels in India (DEVERS 1979, 57).

In Africa and Asia households consume the bulk of fuel wood. In 1976, average per capita fuel wood consumption by households in Asia and Sub-Saharan Africa was estimated at 1.4 m^3, which is over 90% of all consumption (Openshaw 1980, 74). In these regions, most firewood is gathered by users: women in Africa, men and children in Asia. The ratio of fuel wood gathered to that purchased reaches 75% in India, and is much higher than that in Sub-Saharan Africa. A small amount of firewood is produced commercially and hence sold in the market.[2]

Even though most firewood is used by households, its

[2] The ratio of fuel wood gathered by consumers to total fuel wood consumed in The Sudan is 90%. See Chapter 3. In Tanzania, this ratio is estimated at 95% (Arnold and Jongma 1977, 3).

use in industry and local crafts is not insignificant. Industry and services are estimated to use between 15% to 20% of total fuel wood (Ibid., 74; Knowland and Ulinski 1979, 12). In Latin America the ratio is higher. The percentage of non-household consumption of charcoal is expected to surpass that of households in Brazil and in Ghana (DEVERS 1979). Bakeries are the leading fuel wood consumers. In addition, fuel wood is used in a number of important operations such as tobacco curing, fish drying, pottery, and brick-making. It is also used in restaurants, hospitals, and by a number of other service providers, particularly in rural areas.

Fuel wood use extends to transportation, where it fuels trains in Brazil and Tanzania. Wood-burning steamboats were quite common until recently in the Niger and White Nile rivers (Ibid.). Besides, wood provides support for a number of social activities such as funeral services (cremation). In brief, wood is a versatile fuel that plays a critical role in people's lives in less developed countries.

1.2 Biomass and Energy in Sub-Saharan Africa

Within less developed countries, dependence on biomass in Sub-Saharan Africa is striking. Biomass provides about 70% of total energy in this region, though there is considerable variation (Armitage and Schramm 1989, 140-41).

In 1980, over 90% of all households' energy requirements came from fuel wood (Anderson and Fishwick 1984, 12). That represents over 80% of all fuel wood used (Openshaw 1980, 74).

TABLE 4.2

THE STRUCTURE OF ENERGY SUPPLY
IN SUB-SAHARAN AFRICA, 1983

Fuel Type	% of Total Energy
Biomass	72.8
Oil and Gas	18.9
Hydro-power	5.8
Coal	2.5

Source: Adapted from Schramm, 1987.

Household per capita consumption of fuel wood is estimated at 1.03-1.59 m^3 on average (Arnold and Jongma 1977, 3; Openshaw 1980, 74). Few surveys have actually been undertaken, but the true figure probably lies between 1.00 and 2.50 cubic meters.[3] Firewood provides about 63% of total fuel wood consumption. The ratio is higher in rural

[3] Floor (1977, 5) estimated per capita household consumption in Sahelian countries at 0.6 m^3, ranging from 0.48 in Mali to 0.98 in the Ivory Coast. FRIDA (1980, 28, 30) surveyed a sample covering Burkina Faso, Ethiopia, Mali, Mauritania, Niger, Senegal, Sudan, and Togo, and arrived at an estimate of 0.93 m^3. Fleuret and Fleuret (1978, 321) carried out a survey in the town of Kwemzito in Tanzania and found that per capita consumption was 2.6 m^3. Cool climate in that area may explain the high figure. Digernes (1977, 77) estimated that per capita consumption of fuel wood in the town of Bara in The Sudan was about 1.30 m^3. Other estimates for The Sudan are 1.29 m^3 (FRIDA, 28); 2.00 m^3 (Mukhtar 1978, 4).

areas, varying from 78% in Zambia to 96% in Tanzania. The use of crop residues is important in some areas. In Ethiopia, they provide 55% of total energy (Armitage and Schramm 1989, 140-41). Charcoal is particularly important. In The Sudan, it provides 35% of total energy from traditional fuels (Ibid., 140). In urban areas, that ratio reaches up to 70% (Openshaw 1980, 74).

Though households use most fuel wood, its use in local industries is probably larger than is reported. In 1974, the local beer industry in Ouagadougou, Burkina Faso, consumed 14% of total fuel wood used. Brick making in the capital of Chad consumed 30% of all charcoal (Floor 1977, 5). Tobacco curing in Tanzania requires 50 m^3 of fuel wood per hectare every year (DEVERS 1979, 50). Similarly in Mopti, Mali, fish smoking uses 130,000 tons of wood fuel annually (Floor 1977, 5). Restaurants, laundries, schools, and government services also rely on fuel wood.

Pressure on fuel wood resources in Sub-Saharan Africa has been depicted as gaps between the stock of wood and consumption of fuel wood in different countries. The World Bank estimates that the annual rate of consumption exceeds annual additions to supply by 70% in The Sudan, 75% in Nigeria, 150% in Ethiopia, and 200% in Niger. The excess of consumption over the mean annual increment is expected to reach 620% in Niger, and 907% in The Sudan at the end of this century (Anderson and Fishwick 1984, 1-2).[4]

It is believed that the tree stock is declining at an accelerating rate, thereby causing irreversible changes in local ecologies through soil erosion and breach of nutrient cycles. Desertification is the major end result here. Concentrated consumption of fuel wood, particularly charcoal, is associated with the phenomenon of widening desert areas around major towns, such as Ouagadougou, Khartoum, Dakar, and even Kinshasa, which is located in a well forested country.[5]

The period from 1970 to 1980 witnessed considerable expansion in fuel wood consumption. Increases of 76%, 82%, and 75% were projected in Senegal, Niger, and Mauritania respectively from 1970 to 1990 (Floor 1977, 9). In the early 1980s, the effect of economic growth was reflected as a gradual shift towards modern fuels. The share of biomass in total energy use in Sub-Saharan Africa declined slightly from 71% in 1977, to 69% in 1982 (ORNL 1990, 22).

As Table 4.3 indicates, that trend was reversed after the burden of modern energy imports was raised to great heights by oil price increases. The share of biomass in total energy supply has not changed much from 1977 to the

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[4] As discussed in the literature survey, the methodology used to arrive at these figures has been questioned. Figures should be taken cautiously.

[5] In Niamey, Niger, it has been reported that a radius of 50-80 kilometers has been cleared for fuel wood use (Floor 1977, 5). Eckholm (1975, 9) claims that all trees within 70 miles from Ouagadougo have been burnt for fuel.

present. In fact, the average share of wood fuels in energy consumption increased from 71.05% in 1977 to 72.14% in 1987. Total biomass consumption expanded by 19.3% from 1982 to 1987, while consumption of fossil fuels rose by only 3.3% in the same period (Ibid.).

TABLE 4.3

BIOMASS CONSUMPTION COMPARED TO TOTAL ENERGY CONSUMPTION IN SUB-SAHARAN AFRICA, 1977, 1982, 1987

Energy Use/ Year	1977	1982	1987
Total Energy Mn TOE	87.59	98.38	112.53
Biomass Mn TOE	62.23	68.04	81.18
Share of Biomass in Total Energy %	71.05	69.16	72.14
Growth in Biomass %	-	(1977-82) 9.34	(1982-87) 19.31

Source: Adapted from ORNL, 1990.

It can be seen from the previous review that the level of consumption of fuel wood in Sub-Saharan Africa is relatively high compared to other regions. Reliance on charcoal is extensive. Moreover, there does not seem to be a trend or efforts at reducing reliance on biomass energy. As economic growth slows down, imports of fossil fuels are curtailed, and consumption of biomass fuels increases. This is rendered more likely by rapid population growth. The pressure imposed on forest resources by this high level of fuel wood use is investigated in the following section together with other agents of forest depletion.

2. Tropical Deforestation

Forest depletion is a common condition throughout less developed countries, with far reaching local and global implications. The term deforestation is used to describe rather diverse phenomena, ranging from total destruction of forests and land clearance, to gradual degradation of land, and minor disturbances. Generally, it is used to refer to the process of rapid anthropogenic destruction or conversion of forests to other uses.[6]

The term deforestation has been associated with rain forests, where most research is concentrated. That is misleading since much destruction takes place in arid and semi-arid areas around the world. In fact, forest destruction in these areas is more serious than in moist regions because restoration of dry lands is costlier, and more complicated. Extreme land degradation in arid areas leads to desertification, defined as "expansion of desert-like landscapes in arid and semi-arid environments under the impact of human influences," (WRI 1987, 71). It is estimated that by 1984, 1.3 billion hectares in Africa, Asia, and Latin America were at least moderately

[6] In this study, the terms deforestation, forest depletion, destruction and conversion are used interchangeably. Land degradation is applied to the same phenomena in arid, semi-arid, and rangelands.

desertified (WRI 1985, 7).[7]

This phenomenon of land degradation through tree cutting, burning, and overgrazing takes place on a massive scale worldwide, especially in poor countries. It covers both moist and dry lands. It is estimated that the area of forests in less developed countries has declined by almost half in this century, and 40% of closed tropical forests have been altered in some way. The World Resources Institute (WRI) projects that if no measures are taken, at least 225 million hectares in tropical forests will be cleared by the year 2000 (Ibid., 3).

Awareness of this problem surfaced in the beginning of the 1970s, aroused mainly by the Sahel drought. Studies such as Eckholm's (1975) popularized the problem of forest disappearance and the resulting fuel wood scarcity. The condition was recognized with the UN conference on desertification in 1977. Even though initial attention was raised by problems in arid lands, moist tropical forests, particularly in South America, became the focus of research, especially in the 1980s (Repetto and Gillis 1988, Gradwohl 1988). This heightened interest was instigated by rapid forest removal in Brazil since 1980.

The cost of curbing deforestation was estimated in the billions of dollars. In 1985, an international task force

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[7] Moderate desertification implies less than 25% loss of land productivity. Severe desertification reaches up to 50% (WRI 1988-89, 292).

commissioned by the UN Environment Program (UNEP), the World Bank, and the World Resources Institute, identified 56 seriously affected countries, and estimated investment requirements to combat deforestation at $8 billion (WRI 1985, 1).

2.1 Global Estimates of Tropical Deforestation

There is no disagreement as to the presence of accelerated forest depletion in less developed countries. There is, however, less of a consensus on the scale of the condition. Deforestation rates are expressed as areas of converted forest or degraded land in absolute terms, or as a percentage of remaining forest area in a base year (Allen and Barnes 1985).[8] Estimates differ according to definitions, coverage, and methodology. For instance, some studies focus only on closed forests while others include wood lands.[9] Discrepancies also arise from scarcity of data generated mainly by remote sensing techniques, land surveys, and land use studies.

The main sources of estimates of rates of forest depletion are three studies, undertaken over a decade ago. Data for these studies were collected with the specific

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[8] The percentage measure can obscure the magnitude of the problem in cases where countries have large area of land or forest. A small number may give a false impression. Moreover, unless there is an on-going reforestation effort, this estimate will always be rising.

[9] Closed forests include closed natural forests of all classes. This means wet, moist, dry, broadleaved, coniferous, evergreen, or deciduous. They also include managed forests, such as plantations. Forestland is a broad term that includes, in addition to closed forests, open and savanna woodlands, land under shifting cultivation, and agro-forestry (Allen and Barnes 1985).

objective of assessing deforestation for the first time. The studies are: the FAO Production Yearbook (1980); Norman Myers' study for the National Academy of Science NAS (1980); and finally, the FAO/UNEP study of 1982. There is as yet no global survey of deforestation. Results from the FAO tropical forest resources assessment project are not yet available.

Table 4.4 shows the estimates arrived at by each study, and the definition of deforestation used. The three groups of estimates are not strictly comparable since they cover different types of landscapes over different periods of time. However, they convey an approximate picture of forest depletion in less developed countries. The FAO study offers the most comprehensive estimate, covering all types of forests and woodlands. Myers' estimates are limited in coverage, being confined to closed moist forests. The FAO/UNEP study falls in between.

All results show a general decrease in forest area around the world. Myers' estimates are generally higher than those of FAO. It appears that deforestation in forestlands is lower than in closed forests. This is partly the result of the much larger area of the former. In Africa, this result is reversed. Since most deforestation here takes place in savanna lands, closed forests are relatively less disturbed.

TABLE 4.4

ANNUAL RATES OF DEFORESTATION IN
LESS DEVELOPED COUNTRIES, % PER YEAR

	FAO 1980	FAO/UNEP 1982	Myers 1980
Region/ Definition	Change in forestland 1968-1978	Change in closed moist forest 1950-1980	Change in closed forest 1976-1980
Overall	-0.25	-0.54	-0.80
Africa	-0.51	-0.47	-1.40
L. America	-0.29	-0.51	-0.30
Asia	-0.05	-0.66	-1.50

Source: Adapted from Allen and Barnes, 1985.

Myers' results showed that about 200,000 km^2 per year were being depleted in the entire biome. About one half of that was in the form of complete destruction, i.e., deforestation according to his definition. The FAO study generated an estimate of 76,000 km^2 per year, also of total destruction.[10] Thus overall, it is estimated that by the late 1970s between 75,000 and 200,000 km^2 (7.5-20 million hectares) of forests and productive lands were being

[10] Myers explains this discrepancy in terms of the difference in the type of forests covered in each study. Whereas Myers looked at moist forests only, FAO included all woodlands. When confined to moist forests, the two estimates range from 73,000 to 91,000 km^2 annually (Myers 1986, 10).

removed, degraded, or altered annually.[11]

It is important to draw attention to the tentative nature of these figures even though they are produced by highly authoritative bodies in the area of forestry. Myers emphasizes that these are merely educated estimates. Research in this area is far from adequate. In many cases deforestation figures are no more than guesses by local officials. Also, in practice it is difficult to apply these definitions because remote sensing data does not distinguish between different types of forests, for example primary forest and secondary growth.

More recent estimates of deforestation cover a wide range because of the severe dearth of data. In 1985, the International Task Force estimated that deforestation was progressing at the rate of 11.3 million hectares per year, with 7.5 million in closed forests, and 3.8 hectares in open forests. As stated earlier, the Task Force predicted that by the year 2000, over 200 million hectares of tropical forests will have been cleared. This is supported by recent evidence from the London Environmental Economics Center that deforestation in closed tropical forests stands at 7 million hectares per year (Barbier et al 1991, 55). This amounts to an annual rate of 0.60% compared to the 0.54% estimated by FAO/UNEP in 1980.

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[11] These estimates do not consider plantations, but these are not significant (Allen and Barnes 1985).

Myers (1990, 385) estimates the annual rate of tropical forest conversion at 142,200 km^2. That is 1.8% of the remaining forest area in 1989. It also represents a 90% increase from 1979, reflecting the progress of deforestation in the 1980s due to increased activity in the Amazon forest. Repetto (1990) agrees to these estimates, stating that the destruction of tropical forests is a more serious problem than was thought a decade ago. Thus by the 1980s, deforestation was progressing at 11-14 million hectares per year. In terms of remaining forest area, that is more rapid than a decade earlier. In several places deforestation was wider in absolute terms.

2.2 The Regional Scale of Deforestation

Global estimates of deforestation mask a highly differentiated picture. Rates vary considerably among countries and regions. Some areas are undergoing extensive destruction, while others remain largely intact, and many lie in between. The areas being severely depleted include lowland forests in Indonesia, the Philippines, Peninsular Malaysia, Madagascar, and parts of the Amazon region in Colombia, Peru, and Brazil (Myers 1986). Deforestation is serious in mountainous areas in all regions. An estimated 160 million hectares of upland tropical watersheds have already been severely degraded. The worst cases are found in the Himalayan range, the Andean range, Central America, and the Ethiopian highlands (WRI 1985, 8).

On the other hand, the Zaire basin (formerly the Congo) is relatively intact. The mineral endowment of countries in this area, in addition to relatively small populations, have up to now spared forests here from extensive damage. Similarly, vast parts of the Amazon region - particularly in the West - in Brazil are still far from being destroyed (Myers 1986). Between these two extremes lie many areas around the tropics. For example, the outer edges of Central Africa, e.g., in the Cameroon, Myanmar's (formerly Burma) lowland forests, Papua New Guinea, and much of Ecuador, Peru, and parts of Brazil all experience somewhat moderate rates of depletion (Myers 1980, 1990).

On average, it seems that deforestation rates are highest for Africa and lowest in Latin America. Table 4.4 showed the differences in regional rates of deforestation and differences in estimates by the three main studies. Rates for Latin America appear to be within a narrow range among the three studies. There is more agreement on this region where much research has been undertaken relative to other regions. There is less agreement concerning Africa than Asia. This, however, may not always reflect the state of knowledge of the situation in the two regions.

2.2.1 Deforestation in Latin America and The Caribbean

According to the above estimates, the overall annual deforestation rate for this region was 0.29% for forests and woodlands from 1968 to 1978, and between 0.30% to 0.51% in closed forests between 1950 and 1980 (Allen and Barnes 1985, 172). There is much variation in rates within the region. Rates of deforestation are particularly high in Central America. Myers (1986) estimated that by 1990 little would be left of the forests there. Table 4.5 shows deforestation in some Latin American countries.

TABLE 4.5

ANNUAL RATES OF DEFORESTATION IN SELECTED COUNTRIES
IN LATIN AMERICA AND THE CARIBBEAN,
% OF REMAINING FOREST AREA

Country	Forestland Late 1970s	Closed Forest Late 1970s	All Forests 1980-85
Mexico	0.78	1.09	1.30
Brazil	0.24	0.40	0.50
Haiti	3.10	3.20	3.80
Costa Rica	0.38	3.19	3.60
El Salvador	0.69	2.83	3.20
Cuba	2.83	0.13	0.10
Jamaica	0.01	2.05	3.00

Source: Adapted from Allen and Barnes, 1985; and WRI, 1988-89.

As Table 4.5 indicates, the highest rates of forest depletion are in Central America: Costa Rica, 3.19%; El Salvador, 2.83%; and Haiti, 3.20%. More recent data indicate that at least 1.03 million hectares are depleted annually in Central America; 60% of which is in Mexico. Other countries with serious forest depletion cases are Nicaragua, with 12% of the total area deforested in Central America, Guatemala, and Honduras (WRI 1988-89, 286).

Recent statistics show that 6 million hectares are depleted annually in South America; almost 40% of which is in Brazil (Ibid.). This is followed by Argentina, where about 1.55 million hectares of forests are annually depleted. In addition, considerable areas are depleted in Colombia and Ecuador (WRI 1988-89, 286). Table 4.5 shows that in the 1980s, deforestation has worsened everywhere in Latin America, except Cuba.

The best publicized case of deforestation in Latin America is the relatively recent one in Brazil, that hosts 27.5% of all tropical forests. Until the 1960s forests represented about 42% of the total area of the country. By 1990, that figure fell to 25.9%. Forest area in Brazil declined from 3.6 to 2.2 million km^2 (Myers 1990, 376). The estimated annual rate of deforestation in Brazil at the beginning of the 1980s was 0.24% for all forests and 0.40% for closed forests only (Allen and Barnes 1985, 172). The current rate stands at 2.3% of the remaining forest cover.

This is equal to an area of 50,000 km^2 each year, compared to 14,500 km^2 in 1979. This rate is expected to persist in the next few years (Myers 1990, 377).

Deforestation in Brazil has accelerated remarkably in the last decade. The best known case is that of Rondonia in the Southern Amazon region, where the area of forest cleared grew from 8,000 km^2 in 1980, to 60,000 km^2 by 1987, representing about 25% of the area of the province. In the neighboring state of Mato Grosso, the cleared forest area increased from 10,000 km^2 in 1975 to 208,000 km^2 by 1988. It is estimated that by 1988 a total of 400,000 km^2 had been cleared in the region of Amazonia, representing 11% of the original Amazon forest, and roughly 5% of the total area of Brazil (Ibid., 376-77).

Although forest clearance in Amazonia in 1989 showed a decline to 45,000 km^2, that may not reflect a long term trend (Ibid., 378). There is still pressure for further development in the region, including discovery of oil and natural gas in 1987. In addition, there are plans for timber harvesting and provision of large supplies of charcoal for pig iron smelting in Eastern Amazonia. Overall, about 750,000 to 1.36 million km^2 of forests are scheduled for utilization (Ibid., 380).

2.2.2 Deforestation in Asia

Tropical forests are spread over a large number of countries in Asia all the way from India to the Outer Islands of Indonesia. By the end of the 1970s, the overall annual deforestation rate in Asia stood at 0.05% for forestlands, and 0.66% to 1.5% for closed forests (Allen and Barnes 1985, 172). Table 4.6 gives rates of deforestation in some countries. Deforestation in mountainous areas is particularly severe as reflected in the case of Nepal.

TABLE 4.6

ANNUAL RATES OF DEFORESTATION RATES FOR SELECTED COUNTRIES IN ASIA, % OF REMAINING FOREST AREA

Country	Forest land Late 1970s	Closed Forest Late 1970s	All Forests 1980-85
Philippines	2.20	1.02	1.00
Thailand	0.54	3.15	2.40
Indonesia	0.11	0.47	0.50
Nepal	0.11	3.68	4.00
India	0.40	0.28	0.30
Sri Lanka	1.80	1.89	3.50

Source: Adapted from Allen and Barnes, 1985; and WRI, 1988-89.

As Table 4.6 indicates, deforestation is not slowing in this part of the world either. Except in the Philippines and Thailand, rates have risen. Recent studies by the National Remote Sensing Center in India generated an estimate of 1.5 million hectares per year for deforestation in India in the early 1980s. This is ten times the previous estimates. In Thailand, forests have declined from 29% to 19% of the land area between 1985 and 1988 (Repetto 1990, 37).

Deforestation in Indonesia, that has the largest share of tropical forests after Brazil, was estimated at 880,000 hectares per year in the early 1980s (Barbier et al 1991, 56). More recently, it was estimated at 1.2 million hectares a year, thus, giving a rate of 1.4% (Myers 1990, 384). That represents an increase of 36% from previous estimates. Estimates of deforestation in 1980-85 show an area of 2 million hectares a year being depleted in Asia's less developed countries; 31% of that in Indonesia, 19% in Thailand, and 13% in Malaysia. The exception to deforestation trends in Asia is China, where extensive reforestation efforts have been undertaken (WRI 1988-89, 287).

In addition to forest depletion, desertification presents a problem in Asia. This condition is especially severe in Western Asia, in Afghanistan and the Southern parts of the former Soviet republics. The percentage of drylands desertified in Western Asia is estimated at 82% (WRI 1988-89, 291). This is second only to North and Sahelian Africa. Desertification in rainfed crop lands in Asia is the highest in the world.

2.2.3 Deforestation in Sub-Saharan Africa

Deforestation here seems to have a longer history than in other regions. This is partly due to the extensive nature of African cultivation, and the fact that drylands comprise a disproportionate part (65%) of the continent (WRI 1987, 70). Before the twentieth century deforestation presented few problems in Africa due to low population pressure. Droughts occurred occasionally, but recovery naturally followed the return of normal rainfall. Traditional African environmentalism was based on passive environmental management and minimum pressure on the land.

Colonial rule heightened the level of activity in the region with opening of roads, relocation of labor, introduction of cash agriculture, and most of all, extension of rainfed agriculture into drier areas. The need for cash resulting from the introduction of taxation led to shorter fallow periods, thereby imposing further pressure on land. Improvements in public health increased population, and hence drove more people into marginal lands.

Land tenure systems instituted after colonial rule provided an incentive for more destruction. The criterion of " the land to he who tills it" drove people to occupy land just to claim ownership. After independence, governments claimed all residual lands, but they had little capacity of oversight. As a result, land effectively became common property instead of being managed by local chiefs under traditional tenure.[12]

Signs of environmental stress were observed as early as the 1920s. The French geographer Jean-Yves Marchal noted in his diary:

> the problem of deforestation (firewood, building poles, and browse during the dry season) and its effects (erosion) have already attracted attention but without anyone thinking seriously about trying to find a remedy. Deforestation would only get worse and worse. (Richards and Tucker 1988, 81).

In 1936, Auberville - a tropical forester - noted two types of land degradation in Niger: natural, and man-made. He also identified the phenomenon of widening circles around urban centers.

In the 1940s, the majority of Africa's forests was being lost to savanna. Tropical rain forests were converted to high grass savanna, temperate forests to grassland, and dry forests were being lost to tall savanna grasslands. Already one third of all forests had been lost in that manner. If temperate forests are excluded, about 60% and 66% were already lost from tropical rain and dry forests respectively. The actual area of forests in Africa at the time amounted to 531 million hectares, while potential

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[12] The central government in Nigeria controls only 2% of the total land area of the country. The situation in other less developed countries is similar. In Korea, 20% of land is owned by the government (DEVERS 1979, 12).

forests were 1511.5 million hectares (Shantz 1948, 67). Shantz identified the causes of forest conversion as fires and destructive agricultural practices.

Deforestation in Sub-Saharan Africa encompasses a wider area than in other regions and reflects land degradation in two terrains: moist tropical forests, and arid and semi-arid areas to the North of the equatorial region.[13] The status of deforestation in the arid regions can be described as highly uncertain. There are a number of estimates, but their margin of error is probably high due to lack of studies.

The basic estimates by FAO and by Myers indicated that the annual rate of deforestation in Africa was 0.51% for forestland, and between 0.47% and 1.4% for closed forests (Table 4.4). As Table 4.7 illustrates, annual deforestation rates varied from over 5% in the Ivory Coast to 0.10% in Zaire. FAO estimates that between 1976 and 1980 about 1.38 million hectares of land were annually depleted in Africa's closed forests. About 45% of that took place in Nigeria and the Ivory Coast (FAO 1986, 82). Myers estimated that in Kenya 6,181 km^2 of primary forest had already been lost by 1976. While in Zaire, 20,000 km^2 were annually deforested (Myers 1980, 159, 161-162, 166).

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[13] The semi-arid areas can be divided into two belts according to rainfall: the Sahara-Sahel belt where annual rainfall lies between 150-600 mm, and the Sudano-Sahel belt with precipitation of 600-1000 mm a year (Fries and Heermans 1991, 395). The lack of data with respect to forests and vegetation in general in these areas is recently being acknowledged. In 1989, a workshop on management of natural forests in semi-arid areas of Africa was organized by the Swedish Agency for Research Cooperation with Developing Countries to address this issue (Ibid.).

TABLE 4.7

ANNUAL RATES OF DEFORESTATION FOR SELECTED COUNTRIES IN AFRICA, % OF REMAINING FOREST AREA, LATE 1970S

Country	Forestland	Closed Forest
Ivory Coast	3.70	5.40
Benin	0.00	2.83
Niger	1.61	-
Burkina Faso	1.56	-
Congo	0.90	0.10
Zaire	0.23	0.15
Rwanda	1.46	2.13
Ethiopia	0.68	0.23
Kenya	0.05	1.62
Madagascar	0.00	1.50
Somalia	0.94	0.22

Source: Adapted from Allen and Barnes, 1985.

More recent figures have been released for 1981-1985 by FAO and WRI for both closed and open forests [Table 4.8]. These estimates show that Sub-Saharan Africa contributes 23-35% of total tropical deforestation. Between 3.26 and 3.90 million hectares per year were depleted in this region (FAO 1986, 82; WRI 1988-89, 286). According to WRI, three countries contributed the bulk of that result: the Ivory Coast (16%), Nigeria (12%), and Zaire (10%).[14]

[14] The discrepancy between the two reports is generally below 20,000 hectares, except for The Sudan (400,000), Gambia (297,000), and Ethiopia (82,000) (FAO 1986, 82; WRI 1988-89, 286).

TABLE 4.8

FOREST DEPLETION IN SUB-SAHARAN AFRICA BY REGION
MILLION HECTARES PER YEAR,
1981-85

Region	FAO	WRI*
West Africa	1.785	1.507
East Africa	1.245	0.936
Central Africa	0.650	0.636
Southern Africa	0.220	0.180
Total	3.900	3.260

Source: Adapted from FAO, 1986; and from WRI, 1988-89.

Note: West Africa here includes Benin, Burkina Faso, Gambia, Ghana, Guinea, Guinea Bissau, Ivory Coast, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo. East Africa incorporates Burundi, Chad, Djibouti, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Somalia, Sudan, Tanzania, and Uganda. Southern Africa includes Botswana, Lesotho, Namebia, Swaziland, Zambia, and Zimbabwe. Central Africa includes Angola, Cameroon, Central African Republic, Congo, Equatorial Guinea, Gabon, and Zaire. This classification is followed throughout this document.

* WRI estimates are not limited to tropical Africa, thus it includes temperate forests in some countries. These, however, are extremely insignificant.

On the whole, depletion of open forests is almost twice as much as that of closed ones. The annual progress of depletion of closed forests is 1.32 million hectares, while that for open forests is 2.57 million hectares (FAO 1986, 82). The estimate for closed forests shows no change from the 1976-1980 estimate, possibly indicating that estimates have not been updated. Deforestation in closed forests has declined in Ghana, the Ivory Coast, and Madagascar - two of the countries with severe cases in the past. On the other hand, forest removal worsened in Angola, Nigeria, Zaire, and The Sudan.

About 1.04 million hectares of total depletion in open forests is taking place in East Africa. Almost half of that amount is accounted for by The Sudan, where the scale of depletion in open forests is estimated at 500,000 hectares per year. That is the highest figure for any single country in the continent. The largest scale of closed forests' clearance is found in Nigeria: 300,000 hectares per year, followed closely by the Ivory Coast (Ibid.). Deforestation rates are also exceptionally high in Madagascar, where 39% of the original forest area is believed to be present today (Myers 1990, 375).

The pace of deforestation in Central Africa is estimated at 350,000 hectares per year for closed forests, and 310,000 hectares for open forests (FAO 1986, 82). This indicates a slight increase from the 0.35% rate for the period 1950-1980. Zaire, which hosts about 10% of the world tropical forests, and 47% of Africa's forests, accounts for over half of forest depletion in Central Africa. The extent of forest destruction in Zaire is estimated at 180,000 hectares a year, or 0.2% of remaining forest area (Barbier et al 1991, 57). Myers (1990, 383) estimates an even higher rate: 400,000 hectares per year. According to him, that represents 0.4% of the remaining forest area.

To summarize, deforestation is a common phenomenon across less developed countries. In Sub-Saharan Africa, it is relatively extensive, and progressing rapidly. The problem is more serious in open forests, but the process is accelerating in closed forests as well. A few countries have exceptionally high rates. The Ivory Coast and The Sudan are the most prominent cases.

2.3 Causes of Deforestation

There may be little point - apart from deriving broad conclusions - in establishing global causes of forest conversion. What finally matters is the local impact of the condition, no matter how small it may seem from a global viewpoint. Having said that, the main factors behind deforestation are a handful, and are generally agreed upon. The relative significance of each factor is a source of considerable debate.

Disagreement about relative shares results from use of different definitions and focuses. Myers uses a rather limited definition of deforestation: total destruction of forests. Accordingly, his findings show that agricultural expansion is the main factor behind deforestation. His evidence is almost entirely based on humid tropical areas in Latin America and Asia.[15] Extreme lack of data and surveys, and difficulty of measurement also contribute to variation and discrepancies in estimates.

Patterns of forest conversion and destruction vary from one region to another. Nonetheless, there is frequent tendency on the part of researchers to generalize results pertaining to limited areas in order to validate their findings. As a result, most studies reflect extrapolations from other regions. The most documented region is Latin America, with relatively more reliable statistics. Research is heavily focused on rain forests. With regard to arid and semi-arid areas in Africa and other regions, there are not yet studies with similar levels of specificity and detail.

The main factors that lead to forest depletion and general degradation of land in less developed countries can be identified as: 1) agricultural expansion, 2) consumption of wood as fuel, 3) commercial logging, 4) cattle ranching, 5) uncontrolled grazing by livestock, and 6) land clearance for human settlement. Natural factors such as land slides

[15] According to Myers (1990), agriculture is the principal factor behind forest depletion in Bolivia, Brazil, Colombia, Ecuador, Mexico, Peru, Thailand, India, Indonesia, Myanmar, the Philippines, Vietnam, Madagascar, and Nigeria.

and climate change contribute to forest disappearance, but they occur over extended periods of time.

Commercial logging is believed to be responsible for clearance of about 45,000 km^2 of primary forests annually. This represents about 20% of total annual deforestation in the tropics. Still, most researchers dismiss logging despite the fact that it is a wasteful activity. It is estimated that for every tree logged, several are cut down for road clearance. Only the highest grade trees are harvested. Nevertheless, logging is discounted as "not significant in the broad picture, however, because most logged forests are soon occupied by smallscale [sic] cultivators and other farmers." (Myers 1986, 11).

Logging is considered by some authors as the first step in forest destruction because it opens the road for further penetration of forests (Repetto 1990). It is identified as an important source of deforestation in Asia, where ".. virtually all lowland forests of the Philippines and Peninsular Malaysia seem likely to become heavily logged by 1990," (Myers 1986, 12). In Indonesia, where it is the first commercial activity after oil production, logging is believed to be responsible for 16% of forest destruction (Barbier et al 1991, 56).[16]

Commercial logging plays a modest role in deforestation in Africa. It is limited to West, and to some

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[16] Indonesia is a major oil exporter and a member of OPEC.

extent, Central Africa. Timber exports helped finance the Ivory Coast's economic boom in the 1970s. Severe destruction of forests has led Ghana's exports of timber to drop from 124 million m^3 in 1973 to 11 million m^3 in 1982 (WRI 1985, 10). In contrast, the abundance of minerals has spared Zaire's vast forests, 60% of which are considered loggable.

Few authors maintain that cattle ranching and overgrazing by animals are important sources of deforestation. Cattle ranching, which is exclusively limited to South America, is believed to be responsible for the destruction of 20,000 km^2 annually, representing about 10% of total deforestation in the tropics (Myers 1986, 11). Some believe that the total land requirement to accommodate cattle populations accounts for about 50% of all forest conversion. In the Amazon region, that ratio may reach 90% (Seiler and Crutzen 1980, 223). Barbier et al (1991, 56) claim that cattle ranching is responsible for some 38% to 73% of forest alteration in Brazil.

Overgrazing is more important in arid lands, and is associated with desertification. It is common in range lands in the Middle East, Africa and Central Asia. Eckholm (1975) claimed that overgrazing by cattle was the main cause of deforestation in Sub-Saharan Africa and the Rajasthan desert in India. Overgrazing is extremely hazardous because it triggers a process of selfperpetuating soil erosion.[17]

There is little contention that in broad terms agriculture and heavy reliance on fuel wood for energy are the main factors behind tropical deforestation. The particular role played by each is a source of much controversy. On the one hand, there is relatively wide agreement that agriculture is the principal agent of forest removal:

> The spread of agriculture, including crop and livestock production, is the single greatest factor in forest destruction. (WRI 1985, 3).

> By far the most important agent of all, the smallscale [sic] forest farmer--operating variously as shifting cultivator, migrant squatter, or landless "colonist"--is depleting as much as 150,000 square km a year, possibly rather more. (Myers 1986, 11).

Some authors claim that agriculture accounts for over 60% of total forest depletion. In fact, Myers' estimate is 75% (Ibid., 11). Barbier et al (1991, 56) argue that small farmer settlements are the second major cause of forest depletion, being responsible for about 11% of deforestation in the Brazilian Amazon. All these estimates, however, are

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[17] Grazing causes plants to lose their leaves. In response, they draw nutrients from the roots to grow new leaves, thereby causing the root area to shrink. Restoration of severely degraded lands requires some expensive treatment the cost of which may not be recovered by the restored land's productivity (WRI 1987).

based on findings pertaining to tropical rain forests, especially in the Amazon.

On the other hand, there is plenty of evidence that consumption of fuel wood, aggravated by the use of dung and crop residues in severely affected areas, is responsible for destruction of extensive tracts of forests and range lands, thereby, damaging local ecologies beyond recovery:

> In certain localities, however, fuelwood gathering ranks as one of the major pressures to which tropical forests are subjected. Areas in question include Nepal, northern India, ...eastern Madagascar, several sectors in West Africa, and portions of Central America. In these areas... patches of forest are being severely degraded, if not eliminated altogether, by the fuelwood gatherer.
>
> Moreover, the situation today is likely to deteriorate. In many more areas, the pressure of fuelwood gatherers on tropical forests will steadily grow more pronounced, until a sustainable impact becomes a destructive one. (Myers 1984, 115-16).

> Virtually all trees within 70 kilometers of Ouagadougou have been consumed as fuel by the city's inhabitants, and the circle of land "strip-mined" for firewood - without reclamation - is continually expanding. (Eckholm 1975, 9).

So, there is no lack of claims insofar as the damage inflicted on forest resources by either agricultural expansion or fuel wood consumption. In Africa, agricultural expansion contributes to deforestation, but its extent is likely to be overestimated. It is blamed for some of the extensive destruction of forests in the Ivory Coast. In Zaire, landless migrants impoverished by severe economic conditions turn to the forests (Barbier et al 1991). Myers (1980, 151-67) estimated the rates of deforestation due to shifting cultivation at 5.3% for the Ivory Coast, 1.4% for Liberia, 2.2% in Madagascar, and 1.2% in Zaire.

Admittedly, considerable agricultural expansion took place earlier on in Africa during the colonial era, and later on with the introduction of mechanized agriculture in the 1960s. But extended periods of drought since the early 1970s have not allowed considerable expansion in cultivated land. Instead, a lot of migration to urban areas has occurred since then. Moreover, significant neglect has led to decline in agriculture for the last 30 years.

Table 4.9 indicates that evidence does not support that agriculture is the main cause of deforestation in Africa. In the decade 1974-84 total agricultural land in Africa expanded by 4.3 million hectares. Assuming that this is underestimated with a 40% margin of error, this figure becomes 6.0 million hectares, i.e., an annual shrinkage of forests by 600,000 hectares a year. That is strikingly small compared to reported annual deforestation rates [Table 4.8]. In The Sudan, mechanized and traditional agriculture is estimated to account for 2.4% of the total annual loss in forest area (Whitney et al 1985, 8).

TABLE 4.9

EXPANSION OF CROP LAND AROUND THE WORLD, 1974-1984
MILLION HECTARES

	Sub-Saharan Africa		All LDCs	
	1974	1984	1974	1984
Food Crops	92.6	96.5	369.4	396.5
Export Crops	12.3	12.7	57.4	65.5
Total Area	104.9	109.2	426.8	462.0
Change in Food	-	4.3%	-	7.3%
Change in Total	-	4.1%	-	8.2

Source: Compiled from WRI, 1987.

Whereas deforestation due to agriculture is relatively easy to measure because defined pieces of land are cleared for cultivation, evidence on the extent of land deforested as a result of fuel wood consumption can at best be ambiguous. This is so because it is almost impossible to establish, with a reasonable degree of precision, the extent of forest removal or degradation that can be attributed to fuel wood consumption.

In fact, all estimates of deforestation in Sub-Saharan Africa so far reflect measurements of land cleared for agriculture, mainly shifting cultivation. A case in point is Myers' estimates. Myers claims that firewood gathering results in destruction of 25,000 km^2 of forest worldwide annually (Myers 1986, 11). However, his work is focused on moist tropical forests, whereas reliance on fuel wood is highest in dry savanna lands. Myers recognizes this fact, but that is not reflected in his estimates.

Traditionally, deforestation due to fuel wood consumption has been measured only in relation to agriculture. Seiler and Crutzen (1980, 231) estimated that as a world average, 30% of fuel wood requirements are met through shifting cultivation. For Africa, that ratio reaches 50%. A frequently used method is to translate fuel wood consumption into equivalent amounts of wood removed. This, however, entirely misses the point since it is not the amount of wood per se, but the pattern and intensity of wood removal that determines the extent of land degradation.

In the case of charcoal consumption, it is theoretically conceivable to arrive at a more precise estimate of damage to forests, since charcoal is produced in commercial operations, where also defined areas of land are cleared to provide wood. However, with fuel wood and agriculture being intimately inter-related, it is difficult to isolate land cleared for agriculture from that cleared especially for charcoal production. Remote sensing data is unable to distinguish the two.

As a result, there is a tendency to overestimate the role of agriculture in forest depletion generated by the relative ease of measuring this factor. This is aggravated by lack of data for Africa, and the consequent resort to extrapolation from other regions where the contribution of agriculture to forest destruction is more significant. Evidence indicates that the role of fuel wood consumption in deforestation in Sub-Saharan Africa is more significant than is suggested by most of the literature.

2.4. Patterns of Deforestation

The process of forest depletion is not uniform. Patterns of deforestation refer to all the factors that determine the nature and frequency of wood harvesting. These include the particular techniques used, the level of pressure to which certain areas of land are subjected, and the economic motivation behind forest destruction, e.g., subsistence food production vis-à-vis commercial utilization of forests. These elements are crucial to the ecological impact, and to policy designed to contain forest destruction.

The patterns of deforestation differ from one region to another. Even though the area of deforested land may be larger in absolute terms in other parts of the world, the patterns of forest conversion and destruction in Sub-Saharan Africa render its environmental impact more severe, and containment more complicated. At the risk of excessive generalization it can be stated that agriculture and logging are more prominent in the humid tropics, while fuel wood consumption presents more of a problem in arid and semi-arid areas.

Whether deforestation results from private decisions at the household level, or from macroeconomic policy, holds important implications to containment efforts. In Brazil, deforestation is mostly driven by the deliberate government policy of opening up the Amazon region in the past decade for cattle raising, colonial settlement, timber harvesting, and development projects. This government-assisted, highly centralized nature results in rapid large scale depletion. But at the same time, it facilitates regulation through the standard means of fiscal policy.[18]

In the dry tropics, the process of deforestation is slow, unnoticed, and spread over large stretches of land, where millions of scattered individuals and households chip away at wood resources in small daily increments.[19] Deforestation in Africa is rarely based on official policy. In that sense, it does not easily lend itself to control.

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[18] It is argued that government policy such as subsidies and tax exemptions provide an inventive for forest depleting activities that are not otherwise profitable. The removal of subsidies from cattle raising projects in the Amazon is expected to reveal a net loss to investors (Barbier et al 1991). Moreover, the structure of royalties based on the rate of timber removal encourages logging of only the highest quality species. Short term leases undermine interest in the long term regenerative capacity of forests.

[19] A cross sectional analysis of 28 less developed countries indicates that agricultural expansion has a negative impact on forest areas, while wood production affects the area of forest only overtime. The same study shows that there is a strong positive relation between population growth and deforestation rates, and that the relation is stronger for Africa and Asia than it is for Latin America. Accordingly, the study concludes that the future prospects of the pressure of fuel wood use on land is more critical in Sub-Saharan Africa, particularly since its population is still growing at increasing rates while growth rates have declined elsewhere (Allen and Barnes 1985).

Under this regime of deforestation policy is likely to be more effective if it targets microeconomic decisions.

In Asia, government policy has also been behind considerable forest destruction. For instance, the Indonesian government has actively followed a policy of transmigration seeking to move people from the Inner to the Outer Islands. Since 1990, the area of new lands brought under cultivation could average about 500,000 hectares per year. It is estimated that shifting cultivation and planned agriculture resulted in clearance of 500,000 and 235,000 hectares per annum respectively. This covers about 84% of all land cleared (Barbier et al 1991, 56).

Another difference in deforestation patterns is the prominence of charcoal consumption in Africa. Charcoal is a predominantly urban fuel. This results in heavy localized pressure on forest areas. Charcoal production is based on felling whole trees, and clearing vast tracts of land to supply large populations. This is manifested in the phenomenon of desert areas around urban centers mentioned earlier. Rural fuel wood consumers mostly gather branches and twigs, although evidence to the contrary exist (Digernes 1977). This is one of the reasons for the recent emphasis on diffusion of improved stoves in urban centers.

The use of charcoal is particularly damaging to forests due to the currently low efficiency of wood conversion to charcoal. As discussed in Chapter 3, the current charcoal production technology in Africa is not highly efficient in its use of wood. On a global scale, Sub-Saharan Africa produces more charcoal than any other region. Table 4.10 indicates the scale of charcoal production in Africa compared to other regions around the world.

TABLE 4.10

PRODUCTION OF CHARCOAL IN SUB-SAHARAN AFRICA
IN COMPARISON WITH OTHER REGIONS

Region	1980		1989	
	1000 Mt	%	1000 Mt	%
Sub-Saharan Africa	6634	39.0	9130	42.7
Latin America	6534	38.4	7731	36.1
Asia	2862	16.8	3503	16.4
Rest of the World	965	5.7	1000	4.7
Total World	16995		21364	

Source: Compiled from FAO Yearbook of Forest Products, 1989.

Another divergence in the pattern of deforestation between Africa and other regions lies in the returns from the process. In areas where land is cleared for commercial activities, such as logging or large scale agriculture, countries are able to recover part of the value of the forest in the form of foreign exchange, cash income, or employment. The pattern of forest destruction in Sub-Saharan Africa is largely directed toward subsistence food or energy production. In most cases, forest products are not utilized. In the Ivory Coast, the value of timber burnt to clear land for agriculture since 1960 is $5 billion.[20] In Ghana, only 15% of timber is harvested (Repetto 1990, 37).

2.5 Consequences of Deforestation

The impact of deforestation can be evaluated only within a cost-benefit framework since as a multi-product process, forest depletion involves positive returns, and costs or negative benefits that may accrue to certain individuals or are borne by society at large.[21] The benefits derived from deforestation are several. The main ones relevant to Sub-Saharan Africa are agricultural output from land brought under cultivation, and provision of energy. The part of agricultural output that goes to subsistence food needs is closely related to population growth. The remainder of agriculture supports cash crops.

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[20] Manifestations of this pattern can be found in other regions around the world as well. In Brazil, the value of timber lost in this way is estimated at $2.5 billion (Repetto 1990, 37).

[21] Deforestation in and of itself is not adverse, and does not necessarily imply that the condition will not be reversed in the future. Forests in the developed world were severely damaged in the process of economic growth. In particular, mining was responsible for considerable devastation to the environment in the US. Accounts by America's pioneering forester, Gifford Pinchot, reflect that by the turn of the century, "the greatest, the swiftest, the most efficient, and the most appalling wave of forest destruction in human history was then swelling to its climax in the United States; and the American people were glad of it." (Pinchot 1947, 1). However, during this century, the forest area in North America and Europe has actually increased by 5% (WRI 1985, 3).

Foreign exchange proceeds from these are a social benefit.

Biomass energy derived through deforestation is a benefit accruing to households and traditional industries. The foreign exchange savings resulting from reliance on fuel wood in lieu of imported energy are substantial. In 1989-90, total consumption of biomass in The Sudan by all sectors amounted to the equivalent of 2.6 million metric tons of fossil fuel products. In terms of 1989 oil prices this amounts to savings of $468 million.[22] To this must be added the value of output generated by industries fueled by traditional energy.

The two joint products of deforestation, namely agricultural output and energy, are not independent of one another. If returns from agriculture are relatively high, income will rise, and consumers will substitute traditional fuels with modern energy forms. As a result, deforestation due to fuel wood consumption may decline. On the other hand, the poorer the population, the greater is reliance on biomass energy. Thus, in a way deforestation caused by fuel wood consumption is determined or conditioned by deforestation induced by the need to expand the area under cultivation.

In the other direction, if the cost of fuel wood is reduced, in either monetary or real terms, households may

[22] This estimate is based on the following biomass consumption in 1989-90: firewood, 2.7 Mn TOE; charcoal, 1.7; and crop residues, 0.5. The average import price for petroleum products CIF Port Sudan was $180 per Mt in 1989. For conversion factors see the Appendix.

have the opportunity to raise investment in agriculture through improving cultivation practices, or acquiring improved seed varieties and so forth to raise income. Hence, causation also flows from fuel wood consumption to agricultural expansion. Policy aimed at reducing deforestation is likely to be more effective if this relation is recognized and targeted.

With respect to negative impacts, deforestation embodies two types of economic costs: private and social. Private costs are those borne by a few or certain individuals or groups. Those are people who directly feel the burden of deforestation in the form of either an increase in the price of fuel wood in urban areas, or in lengthening of the time required for fuel wood gathering in rural areas.

Evidence indicates that, with few exceptions, real fuel wood prices rose sharply in the 1970s. Real prices in India doubled between 1970 and 1980. In Turkey, they increased by 400% in the same period (FAO 1988, 32). In the early 1970s, on average, fuel wood purchases absorbed 20-30% of households' budgets in West Africa. In Kathmandu, Nepal, prices of fuel wood increased by 300% from 1972 to 1975 (Eckholm 1975, 6). It is estimated that in the absence of reforestation, at least 3 billion people will face exceedingly high fuel wood prices by the year 2000 (World Bank 1983, 46). This projection overlooks market adjustment to shortages as will be discussed momentarily.[23]

On the other hand, real prices of fuel wood remained stable, or declined in several countries after 1980, though they have not risen up again to their pre-1970 levels. For instance, in Thailand, fuel wood prices rose by 465% from 1970 to 1983, but then declined by about 12% till 1986. In Togo, prices rose by over 200% from 1975 to 1980; by 1982 they had declined by 23%. In the Ivory Coast, prices declined by 42% between 1980 and 1985 (FAO 1988, 32). These declines probably reflect results of reforestation efforts or conversion to fuels other than wood induced by the earlier rise in fuel wood prices as part of a market adjustment process.

The labor time expended in the search for fuel is drawn away from other productive economic or social activities such as food production or child care. Volumes have already been written on the hardships that local populations, mostly women and children, incur every day in the search for firewood. It is estimated that, on average, it takes from 100 to 300 workdays a year to secure a household's fuel wood requirements in the rural areas of poor countries (WRI 1985, 5).

[23] In some instances it is claimed that fuel wood costs more than the meals it is used to cook. In these cases, where the number of meals is constrained by the amount of fuel secured, the scarcity of fuel wood is believed to be reflected in nutritional deficiency, although evidence is hard to come by. It is postulated that dietary effects of fuel wood shortage include reduced number of meals, inadequate preparation of special foods, e.g., for infants and the invalid, elimination of fuel intensive-dishes, consumption of raw foods, reduced expenditure on food, and higher human energy requirements for collection of fuel wood. Although these effects may be quite legitimate, they are not well substantiated (Unasylva 1990).

The social costs of deforestation are those borne by everyone in society, though not necessarily equally. As such, they reflect the full extent of the externality of deforestation. Most of these costs involve some form of ecological damage. Destruction of the productive capacity of land is the main hazard of deforestation in poor countries, especially in arid areas where extreme degradation leads to desertification. The link between deforestation and decline in agricultural productivity is described as follows:

> The removal of tree cover can further reduce agricultural productivity by loss of the benefits trees provide for farms. Widespread loss of vegetation reduces the effectiveness of rainfall by decreasing the amount of water that percolates into the ground. Water runoff increases, erosion accelerates, the water table is lowered, and springs and wells dry up. (Ibid., 7).

Decline in agricultural productivity is devastating because, as noted earlier, in many regions agriculture is the main or only source of foreign exchange. This is the type of cycle in which Sub-Saharan Africa has been trapped for over a decade now.[24] The cost of land restoration is relatively high in arid areas. In Ghana, elimination of savanna forests increased soil erosion from less than a ton

[24] Granted, other factors, such as shortage of inputs, inappropriate pricing policies, climate change, and shortening of fallow periods, contribute to the decline of African agriculture.

to over 100 tons per hectare per year. The resulting nutrient loss is 40% higher than is compensated for by use of fertilizers (Repetto 1990, 38).

Most ecological damage from forest depletion is off-site and collectively borne. One example is the increase in the incidence of flooding. Deforestation causes flooding by removing the tree cover that reduces run-off. This directly affects inhabitants of lowland watersheds such as in Ethiopia and the Himalayan range. Communities living in these areas also bear the private costs of displacement by floods.

Another problem is increased siltation resulting from the movement of soil following tree removal. High siltation leads to reservoir filling, and hence, interruption of hydro-power generation.[25] Moreover, obstruction of water ways and irrigation systems results in crop loss, and blockage of navigation. Fisheries are destroyed as a result of increased sedimentation (Ibid.).[26] Expenses towards flood control, cleaning of dams and water ways, as well as lost power output, and fishing potential are all incurred by society.

Another consequence of forest destruction is the loss

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[25] Progressive deforestation in the Central Region of The Sudan is believed to be behind increased annual flooding of the Damazine Lake, which supplies the largest generator of hydroelectric power in the country. This results in frequent disruption of electricity generation with implications for productivity in all sectors served by that network (Mukhtar 1981).

[26] Other offsite costs of deforestation include dust storms resulting in health problems, and in damage to equipment entailing high repair costs. They also include damage to crops by pests that may have otherwise obtained their sustenance from live trees (Whitney et al 1987).

of habitat leading to shrinkage in wild life. This is particularly important for countries where tourism is a significant source of foreign exchange, as is the case in several countries in Sub-Saharan Africa. The range of the African elephant is estimated to be one third its original size (WRI 1988-89, 91). Rates of habitat loss are estimated at 87% in Rwanda and 85% in Sierra Leone (Ibid., 94).

Change in habitat is also believed to present a threat to genetic diversity. Tropical rain forests have one of the most diverse ecosystems in the biosphere, hosting over one half of the total number of plant and animal species presently known. In addition to their importance for ecological considerations such as climate, tropical forests are believed to hold potential for scientific research, though this is not exactly known since less than 1% of all tropical plants have been catalogued for potential uses (WRI 1985, 12). Biological extinction thus involves ecological damage, and loss of gains from potential scientific breakthroughs.[27]

The loss of recreational value from forests and services they provide is borne by everyone, if not equally. As such, this case does not represent an aggregate externality. Option values, particularly, are not expected to be equal. Although it may be inappropriate to speak of

[27] This does not represent a viable opportunity cost to less developed countries at the moment, except if the technology and the products were made available to these countries at low cost.

the option value of forests in reference to Sub-Saharan Africa due to high social discount rates that limit choice matrices to the immediate time period.

It is not possible to state whether deforestation involves a net cost or benefit in the absence of the specific value of each of the factors enumerated above. However, in all cases close attention must be paid to ecological damage and the possibility of irreversible outcomes (Krutilla and Fisher 1975). Forests supply a wide range of economic and ecological goods and services, extending from building materials, food, medicine, and fodder, to energy, shelter, and recreation. In the tropics, one of the most important services of forests is protection of soil from erosion by wind and rain because tropical soils are especially fragile.[28]

Accordingly, the economic valuation of forest products must take into account all the market and non-market functions forests provide. Because of external effects, some of these functions may not be reflected in the prices of forest products. For instance, timber traders do not pay any ecological premium. The current price of timber does not reflect the cost of replanting trees, especially given that the regenerative power of tropical forests is low, taking long periods of time to recover.

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[28] In fact, most of the nutrients in tropical forests are held in the trees, in contrast to temperate forests where the bulk of the nutrients reside in the soil.

The social costs of deforestation in The Sudan have been estimated at a present value of $275.7 per hectare in 1982 dollars discounted for 10 years. These costs are in the form of loss of nitrogen produced by Acacia trees, loss of animal feed through destruction of trees, loss of soil nutrients, loss of moisture storage, and loss of nutrients stored in wood.[29] When the benefits derived from the process of deforestation are accounted for, the net social returns on deforestation are $-40.00 per hectare for the same discounting period (Whitney et al 1987, 330). This means that deforestation is still adverse even after including the benefits it generates.[30]

These results are inadequate because many off-site costs of the type enumerated above are not included. Nor is the opportunity cost of the time allocated by households for fuel wood gathering. The main drawback of this type of study, however, is excessive aggregation, whereby the localized impacts of forest removal are not given any attention. Summarizing the cost of deforestation in a single figure for an entire country is misleading. Benefit-cost ratios are more meaningful on the basis of specific

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[29] Acacia trees are leguminous species dominant in the African Sahel area, they are known to enhance crop yields in semi-arid areas. Acacia Senegal is used for production of gum Arabic. Acacia Albeda (Hashab) is preferred for firewood production.

[30] When the opportunity cost of land is set at zero, the net social returns from deforestation turn positive, reaching $67.00 per hectare for a 10 years discounting period. The authors assume that 39% of the land deforested annually lies in remote and abandoned areas. This may be true for some of the land used for charcoal production. But firewood is gathered from areas surrounding villages and inhabited areas that are often used for growing food or cash crops.

regions or projects.

By and large, deforestation must be analyzed as a complex multi-product process that generates both positive and negative outcomes. The relative significance of each, within specific contexts, has to be established before any policy recommendations can be offered. Looking at deforestation from the single-minded perspective of fuel wood scarcity is inadequate, and neglects benefits accruing to the same population by way of revenue from agriculture and satisfaction of energy-using household tasks.

Within a welfare maximizing framework, households are equating, at the margin, their benefits and costs from the use of forests. However, since their decisions involve social costs due to the presence of external effects from deforestation, there is need for intervention. The preceding sections indicated that regardless of the above, and aside from issues of resource allocation, households incur a financial, physical, and psychological burden from deforestation that warrants mitigation on social grounds.

In Sub-Saharan Africa, extreme resource scarcity dictates optimum allocation of these resources. Forest depletion in the region is largely influenced by heavy reliance on traditional fuels. Understanding the relation that holds the two together is essential for identification of the areas most responsive to intervention. The following section addresses this issue.

2.6 Deforestation and Fuel Wood Prices

The relationship between forest depletion and fuel wood prices is bi-directional; causation flows from forest resources to prices, and then in the opposite direction. The fuel wood market reflects three elements. The first is wood resources in the form of natural forests, plantations, scattered trees, or grassland. These can be private, but in Sub-Saharan Africa, they are mostly public or communal. The second element is wood consumers, i.e., households and industries or services. Finally, wood producers include households, mostly in rural areas, and commercial producers of fuel wood, namely the charcoal industry.

The use of forests is sustainable as long as the wood cut does not exceed mean annual tree increments. It is the violation of this condition that results in forest depletion. Wood resources as a stock are thus impacted by a flow of consumption-production decisions from economic agents. As in any market situation, deviations from equilibrium are handled through price and quantity adjustments.

As Figure 4.1 indicates, decisions taken by consumers and producers impact wood resources, shown by arrows. Any excess demand or supply is transmitted to fuel wood prices, which results in further quantity adjustments. In the case of a price drop for instance, producers of fuel wood will reduce supplies, while households increase their purchases of fuel wood. Producer-households do not directly respond to prices but to resulting changes in wood supplies, reallocating their time to reflect a different fuel wood situation.

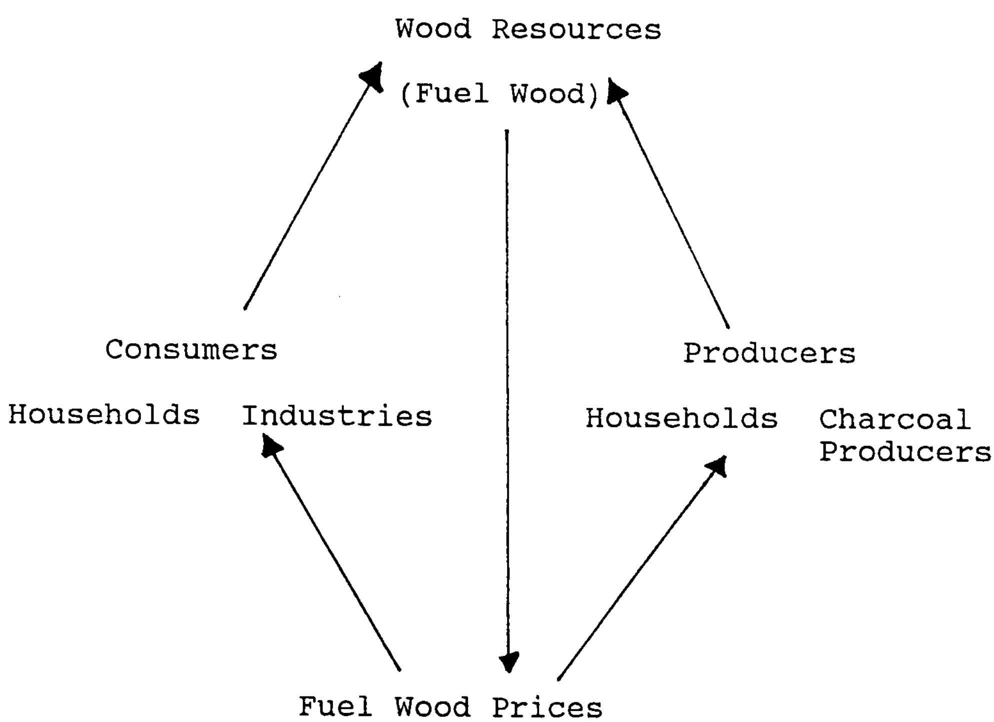

Fig. 4.1 The Market for Fuel Wood

Quantity adjustments are determined by supply and demand elasticities that indicate the magnitude of responses from consumers and producers, and consequently, their impact on forest resources. If, ceteris paribus, demand is highly price elastic, then deforestation will slow down relatively rapidly following a price increase. If supply elasticity is relatively large, pressure on wood resources imposed by producers seeking to take advantage of the rise in price will be sizable.

In the absence of tree planting, deforestation represents an inward shift in the fuel wood supply schedule. Economic theory states that if a shortage of fuel wood develops, fuel wood prices will move upwards to clear the market. Consumers will adjust their consumption levels downwards, producers moving in the opposite direction since larger quantities can now be supplied at the higher prices. The new market position will be determined by the net quantity adjustment. In all likelihood, the new equilibrium position will be attained at a smaller quantity and a higher price than the initial ones.

The process described above will be repeated in successive time periods with supply shifting further to the left, and prices rising in the pattern indicated in Figure 4.2. However, this pattern is true only in two cases. The first is in the short run, which is determined by the time required for trees to be planted and be ready for harvest. This period varies considerably, but instances of premature cutting of trees for fuel have been reported, specifically in The Sudan (Digernes 1977). Barring irreversible damage, in the long run supplies will be increased in response to higher prices.[31]

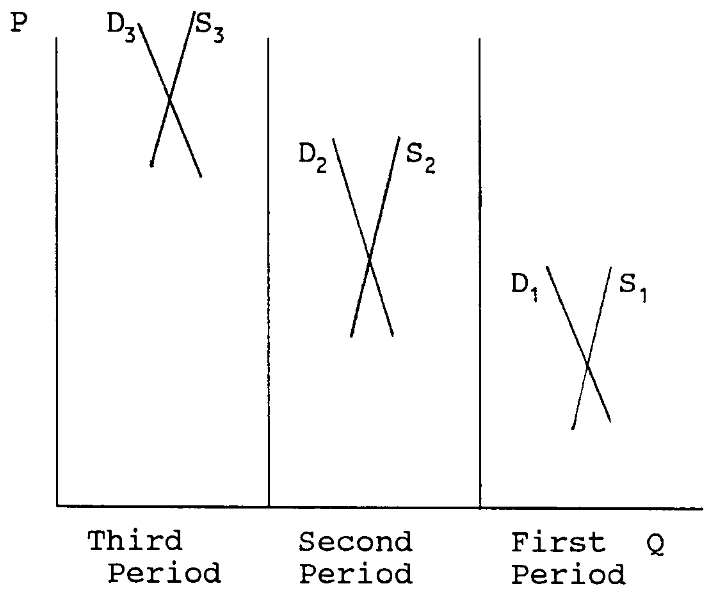

Fig. 4.2 The Effect of Deforestation on Fuel Wood Supply and Price in the Absence of Reforestation, and Quantity Adjustments

The other case where the process described in Figure 4.2 is likely to arise is if quantity adjustments in the fuel wood market are relatively small. This is indicated by low elasticities. In this event, the bulk of market adjustment will be borne by fuel wood prices. The relation between deforestation and fuel wood prices is likely to be of the shape described above because market adjustment to

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[31] At the present time it appears that there is still room for expansion of fuel wood supplies if prices rise sufficiently. As explained in Chapter 3, forest resources in Southern Sudan are not utilized due to high transportation costs, as well as political unrest. Higher prices may change the profitability of this situation.

forest depletion will be reflected in higher prices more than in quantity adjustments.

It is believed that in Sub-Saharan Africa the fuel wood market is characterized by low elasticities on both the demand and supply sides. Earlier in this chapter it was noted that some price adjustment has in fact taken place where prices generally declined after a period of rapid increases in the 1970s. Nevertheless, that does not seem to have induced a proportionate change in fuel wood consumption, as evidenced by the acceleration in deforestation.

Apart from reforestation, which directly augments wood resources, any policy for combating deforestation induced by fuel wood consumption operates through fuel wood quantities and prices. The effectiveness of improved stoves in slowing deforestation can be measured against this background. Chapter 5 investigates the implications of the above framework for improved stoves.

3. Implications for Global Warming

Climate change is the global external effect of forest depletion. Metaphorically speaking, less developed countries are subject to what can be described as an "environmental mandate" because their freedom of following any particular path of economic growth is limited by the prospect of global warming and other environmental problems of international significance. The mandate is enforced through the possibility of withholding economic cooperation and aid by developed countries. As a result, global warming adds an incentive for poor countries to control deforestation.

Moreover, inclusion of this factor may modify the relative roles of agriculture and fuel wood consumption as agents of environmental change because of the role biomass burning plays in the global carbon cycle. This section reviews the issue of global warming, the role of biomass energy in that respect, and the implications for Sub-Saharan Africa.

3.1 The Greenhouse Effect

Forests represent one of the carbon sinks in the biosphere since plants absorb carbon in the process of photosynthesis.[32] The decomposition of vegetation releases this carbon content into the atmosphere, where together with other greenhouse gases, it creates the greenhouse phenomenon.[33] Greenhouse gases allow short wave solar radiation to penetrate the earth, and absorb outgoing long wave infrared radiation that would otherwise carry away heat energy, and hence raise the temperature of the earth

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[32] The other carbon storage sinks or reservoirs are oceans, surface water, soil, rocks and sediments, including fossil fuel deposits, and the atmosphere.

[33] Slightly less than half the carbon emissions stay in the atmosphere. The remainder is absorbed in other sinks.

(Bolin 1986, NAS 1983).

Carbon dioxide (CO_2) is the main greenhouse gas besides methane (CH_4), chlorofluorocarbons (CFCs), and nitrous oxide (N_2O), which differ in their heat trapping efficiency. The relative thermal effects of these gases are 72% for CO_2, 25% for CFC_s, while CH_4 contributes 3% to the heating effect of all trace gases. Methane is a natural gas released in various activities, including rice cultivation, biomass burning, and cattle breeding. It has an atmospheric life span of ten years. Its current global concentration level is 1.7 ppm, increasing at an annual rate of 1.0% (ORNL 1990, 9).

Nitrous oxide is released from biomass burning and application of nitrogen fertilizers. Its concentration levels are low at the moment (0.3 ppm), rising at 0.3% annually, but it has a residence of 150 years in the atmosphere. CFCs are chemical gases that are not naturally found in nature, or may be found in extremely low concentrations. They are used in industrial products and processes. Their concentrations are very low but their relative heat efficiency of 22,000 times that of CO_2 makes them extremely powerful (Ibid.).

Co_2 concentrations in the atmosphere have increased by about 25% in the last 100 years. More recently, they increased from 315 ppm in 1958 to 343 ppm in 1984 (Bolin 1986, 2). It is believed that the present concentration level is 348-351 ppm, increasing at an annual rate of 0.4-0.52% (ORNL 1990, 9). Based on the assumption of doubling concentrations, the earth's temperature is expected to rise by 1 to 5 degrees celsius by the middle of next century (NAS 1983).[34]

If it occurs, the rise in temperature is expected to cause profound climatic changes around the globe. The expected effects include changes in agricultural seasonality and hence geographic distribution. For instance, the corn belt is expected to expand upwards and to the East. Impacts will extend to forests, and to the hydrological cycle, thereby affecting water supplies. Potential risks, though not highly likely, include melting of ice sheets, that will raise sea levels by 1-2 cm/year (Bolin 1986, 18).

The temperature change, however, is still controversial. Some scientists believe that, if it occurs, the increase in temperature will be a negligible 0.5 to 1.5 degrees celsius (Lindzen 1992, 89). The controversy is mounted on questioning the assumptions and climate models used. Lindzen states that "as a scientist, I can find no substantive basis for the warming scenarios being popularly described." (Ibid., 87). On the other hand, some economists

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[34] Most estimates of temperature change fall in that range; the Nuclear Center in Germany (1984) estimates it at 1-3^{o} C, and Bolin et al (1986) have a slightly wider range: 1.5-5.5^{o} C; Schneider (1989, 13, 24) puts it at 5^{o}. Global temperature has risen by 0.5^{o} in the last 100 years (Bolin 1986, 17).

maintain that if and when global warming occurs, the cost of adjustment will not be too severe (Schelling 1992).

Granted there is still considerable uncertainty about the scale and regional pattern of warming. Moreover, not all the consequences from global warming are expected to be adverse. An increase in rainfall in the African Sahel is one case. Also, increased carbon concentrations are known to enhance plant growth. Nevertheless, uncertainty in itself represents a good motivation for acting - cautiously - to avoid calamitous ends.

Estimates of global warming are inherently uncertain because they depend on four steps, two of which are extremely volatile. The first step is estimation of the future type and level of economic activity, specifically, consumption of fossil fuels and deforestation rates, being the prime sources of CO_2 emissions. As is well known, future estimates of fossil fuels' consumption depend on highly unreliable price forecasts.

The two intermediate steps: estimation of carbon and other greenhouse gas emissions and concentrations are complex, but they are less uncertain once the future pattern and level of economic activity are ascertained. The final step is to make the leap from concentrations to resulting change in climate, and specifically, temperature. This involves some speculation, especially about the regional distribution of change.

Estimates of present global annual carbon emissions range between 6 billion (Ibid., 4), and 8 billion tons of carbon (Myers 1990, 397). The former figure is likely to be too conservative because it does not include some important variables that will be explained later in this chapter. Earlier on, Woodwell et al (1983, 1081) estimated that net global releases of carbon from all terrestrial biota, including forests and soils was 1.8-4.7 billion tons annually; with land clearance for agriculture, especially in the tropics, being the largest biotic source.[35]

3.2 Global Warming and Less Developed Countries

Depending on source, carbon emissions from tropical deforestation stand between 0.6 and 2.4 billion tons of carbon annually (Myers 1990, 395; Repetto 1990, 36; Barbier et al 1991, 57).[36] This represents about 10% to 40% of global carbon emissions. The remainder is contributed by fossil fuels.[37] Around 60% of Myers' 2.4 billion tons per year estimate comes from closed tropical forests. The relative shares of different economic activities in carbon

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[35] These figures are based on the Carbon Dioxide Assessment Committee CDAC (NAS 1983). Earlier estimates of carbon releases from the biosphere include the World Climate Program (1981), 0-4.0; The German Nuclear Center (1983), 0.5-4.0; and Bolin et al (1986), 1.6 ± 0.8 billion tons of carbon per year. See Bolin 1986, 4.

[36] The World Resources Institute (WRI 1990-91, 348-49) estimates CO_2 emissions from land use changes in less developed countries at 1.58 billion tons a year.

[37] Some authors tend to discount the future effect of deforestation by assuming that all forests will be depleted sometime in the next century anyway. This is referred to as the physical limit on deforestation (Bolin 1986).

releases over the past century are divided as follows: 57% fossil fuel burning, 20% deforestation, 9% farming and livestock, and 14% natural sources (Ogawa 1991, 23-4).

Global fossil fuel emissions stood between 5.5 and 6.0 billion tons of carbon in 1987 (Myers 1990, 395; ORNL 1990, 24; Ogawa 1991, 25). Annual releases from fossil fuels were smaller than those from biota until 1960. But the share of biotic releases, i.e., fuel wood consumption and agricultural expansion, is rising faster, most probably because fossil fuels' consumption in less developed countries is, for the moment, restrained by the high cost of imported energy.[38]

Total carbon releases from fossil fuel burning in less developed countries were estimated at 1.7 billion tons of carbon in 1987. This represents a 115% increase from the 1973 emissions level of 0.79 billion. The share of the poorer nations in global fossil fuel emissions grew from 17% to 28% during that period (Ibid.). This share is expected to increase considerably.[39] The share of Africa

[38] Annual growth rates of modern energy consumption in less developed countries fell from 6.9% in 1965-80 (the period that witnessed rapid expansion in carbon emissions), to 4.0% in 1980-89. The corresponding decrease for Sub-Saharan Africa was from 5.7% to 2.5% for the same period (World Bank 1991, 212-13). This has taken a rather severe shape in many African countries, where annual growth rates for the two periods were:

Somalia	16.7% to 1.8%
Burkina Faso	10.5% to 0.0%
Togo	10.7% to -1.3%
Ghana	7.8% to -2.6%

[39] A study of CO_2 emissions from 9 major less developed countries reveals that their emissions' level was 845 million tons in 1985. The study projects that CO_2 emissions will rise by four fold by the year 2025. India and China contributed over 70% of emissions from these countries (Sathaye and Ketoff 1991, 161).

and the Middle East in total global carbon emissions is about 7% (Ibid.). ORNL (1990) estimates that in 1986, Africa contributed 3% to global carbon emissions. That estimate, however, includes South Africa, which makes a large contribution to total emissions.

The share of tropical deforestation in all greenhouse gas emissions is estimated at 18-19% (Myers 1990, 396). Methane emissions from less developed countries are particularly high (64%) due to cattle raising, rice cultivation, and biomass burning (ORNL 1990, 9). CFCs have been phased out in the US under the Montreal Treaty, but less developed countries' releases of these gases are increasing rapidly. These gases do not present a serious problem because the cost of discontinuing their use is relatively low (Nordhaus 1991).

Even though concentrations of other greenhouse gases are increasing rapidly relative to those of carbon dioxide, it is the latter that presents a significant problem in terms of the cost of abatement. It is estimated that replacement of CFCs can be handled by a $5/ton of carbon equivalent tax: a rather modest penalty. The cost of reducing CO_2 emissions ranges from $55 to $700 per ton for specific technologies, taxes or geo-engineering solutions (Ibid., 42-3, 54).[40]

[40] Geo-engineering technologies are advanced devices to reduce concentrations of greenhouse gases in the atmosphere. They include ideas such as changing the earth's albedo, injecting iron into the oceans to raise their carbon absorptive capacity, and shooting particulates in the

3.3 Greenhouse Emissions in Sub-Saharan Africa

Total carbon emissions from Sub-Saharan Africa were estimated at 154.5 million tons in 1987 (ORNL 1990, 25).[41] That represents about 2.5-3% of total global emissions. The picture here is quite different from other regions, though. As Table 4.11 indicates, over 75% of total carbon emissions (116.97 million tons) comes from biotic sources, while the remaining 25% comes from burning of fossil fuels. As such, the contribution of this region to global fossil fuel emissions is rather insignificant (0.68%).[42]

Similar to other regions, releases from biotic sources are increasing much more rapidly than from fossil fuel burning. Fossil fuel emissions expanded by 23%, while those from biomass increased by 30% from 1977 to 1987. From 1982 to 1987 the difference between growth rates of the two types of fuel is even higher. This trend is projected to continue, and perhaps, accelerate.[43] With the poor economic performance in the region, and increasing inability to maintain imports of modern fuels, more consumers are likely to revert to traditional fuels.

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stratosphere to cool-off temperatures. See Nordhaus, 1991.

[41] Other greenhouse gases were not considered in this study because they were believed to be nonsignificant.

[42] When South Africa is considered, this share climbs to 2.1%.

[43] The study projects a linear growth rate for fossil fuels' consumption until the year 2010.

TABLE 4.11

CARBON EMISSIONS IN SUB-SAHARAN AFRICA
BY SOURCE AND PERCENTAGE CHANGE FROM ONE PERIOD TO ANOTHER,
MILLION TONS

Source of Emissions	1977	1982	1987
Biomass*	90.03	98.25	116.97
% Change	-	9.13	19.05
Fossil Fuels	30.38	36.34	37.54
% Change	-	19.62	3.30
Total	120.41	134.59	154.51
% Change	-	11.78	14.80

Source: Adapted from ORNL, 1990.

Notes:- * Biomass includes fuel wood cutting and agricultural expansion.

The regional distribution of emissions is indicated by Table 4.12. East Africa has the highest level of biomass emissions. This finding does not come as a surprise since this region has the highest biomass consumption in the continent. Total emissions in Southern Africa are growing faster than any other region. Emissions from biomass during 1977-87 rose fastest in Central Africa even though deforestation in terms of land area was higher in East and West Africa.

Nigeria is responsible for almost 30% of Sub-Saharan Africa's carbon emissions, and its potential for further increases is larger than most countries in the area. Projected annual population growth for Nigeria is 3.2% to the year 2000. By the year 2025, its population is expected to reach 298 million (World Bank 1991, 254). Besides, Nigeria has the capacity for increasing its consumption of fossil fuels from its domestic resources. Thus, this country furnishes an important opportunity for intervention.

The Oak Ridge National Laboratory (ORNL) study considers CO_2 emissions from the energy sector in the continent to be "relatively minor," and therefore sees no need for concern. Dismissing emissions in Sub-Saharan Africa as insignificant is unfortunate because arresting the problem as this early stage is most likely more cost-effective, especially given that the future trend in emissions is upwards. Moreover, the study does not mention estimates by other authors of significantly higher CO_2 emissions from this region. These are discussed momentarily.

TABLE 4.12

CARBON EMISSIONS IN SUB-SAHARAN AFRICA
BY REGION, MILLION TONS
1977, 1982, 1987

Region	West Africa	East Africa	Central Africa	Southern Africa
1977				
Biomass	33.74	39.69	11.07	4.55
Fossil Fuel	17.61	5.04	3.91	3.61
Total	51.35	44.73	14.98	8.16
1982				
Biomass	38.69	40.91	11.89	5.60
Fossil Fuel	21.90	5.03	5.58	3.59
Total	60.59	45.94	17.47	9.19
% Change 1977-1982	17.99	2.70	16.62	12.62
1987				
Biomass	44.86	49.65	15.17	6.08
Fossil Fuel	20.75	5.24	5.79	5.51
Total	65.61	54.89	20.96	11.58
% Change 1982-1987	8.28	19.48	19.98	26.00
% Change in Biomass 1977-1987	32.96	25.09	37.04	33.63
% Change in Total 1977-1987	27.78	22.71	39.91	41.91

Source: Adapted from ORNL, 1990.

Notes:- For composition of regions, and rates of deforestation, see Table 4.8.

In any event, the study suggests that the greatest opportunities for reducing carbon emissions in Africa will be furnished by improved stoves. Even a 10% rate of improved stoves' penetration is estimated to result in significant emissions' reduction, though this was not quantified. This recommendation implicitly states that deforestation from fuel wood consumption in the continent is significant. Aggressive forest protection, i.e., halting of forest depletion, can reduce emissions by 62 million tons a year at a cost of $25-115/hectare, while agro-forestry reduces emissions by 38-132 million tons at $50-150/hectare (ORNL 1990, 96).

The share of Sub-Saharan Africa in global carbon emissions from tropical deforestation is estimated at 20%.[44] Depending on future trends in deforestation, this share may become quite significant.[45] A shift of commercial logging operations is expected to take place from South America and Asia to Central Africa as a result of international pressures on the former regions. Moreover, these projections assume that no economic development takes place in Sub-Saharan Africa.

The contribution of agriculture to methane releases in

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[44] A 30% decline in emissions is projected by the study by the year 2000, assuming no change in the present rates of deforestation. The decline is attributed to reduction in forest area. But there are still vast areas of untouched primary forests in Central Africa.

[45] For instance, it is estimated that if the rate of deforestation in Zaire increases from the current 0.23% to 0.6%, the share of Sub-Saharan Africa in carbon emissions from tropical deforestation will rise to 30% (ORNL 1990, 95).

Sub-Saharan Africa is probably negligible; use of fertilizers is limited, and cattle ranching is altogether absent.[46] CFCs are not a significant source of emissions here due to the narrow scope of use. Logging has no bearing on global warming because even though it releases about the same amount of carbon as agricultural expansion, forests store carbon again when they recover. However, all these estimates neglect biomass energy as a potential source of carbon emissions.

3.4 Biomass Energy as a Potential Source of Greenhouse Gas Emissions

The previous estimates overlook the fact that in addition to deforestation, fuel wood consumption may contribute to global warming directly through emissions from wood burning. This ultimately depends on the net carbon release after new plant growth is taken into consideration. Though they did not mention it explicitly, Seiler and Crutzen (1980) first drew attention to the role of biomass burning in global warming via the release of a number of trace gases including carbon monoxide (CO), CO_2, CH_4, and N_2O, in the atmosphere.

The authors estimated that gross global carbon releases from biomass burning in forest fires were 2-4

[46] In 1989-90, fertilizer consumption in Sub-Saharan Africa in hundreds of grams of plant nutrient per hectare of arable land was 89 grams, compared to an average of 833 grams for less developed countries, and almost 3,000 for developed countries (World Bank 1992, 225).

billion tons per year for the period 1960-75. The net carbon flux, i.e., total emissions net of the amount of carbon absorbed in plant regrowth, was estimated at 0.1-0.2 billion tons per year (Ibid., 232, 239).[47] Over 70% of those emissions took place in tropical and subtropical regions, especially in the dry savanna mostly located in Sub-Saharan Africa. In terms of CO_2 emissions prevailing at the time of the study, these figures make a significant difference.

Other authors have arrived at significantly higher estimates of carbon emissions from biomass burning. Wong (1978, 197) estimated carbon emissions from forest fires at 5.7 billion tons per year, even though his estimate does not include biomass burning in the savanna. His net estimate was 1.5 billion tons a year. A higher estimate of 7 billion was independently arrived at by Root and by Bach (Seiler and Crutzen 1980, 234).

In a recent study Paul Crutzen states that African fires are " the world's leading contributor to pollution coming from the burning of vegetation."[48] Crutzen claims

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[47] The host of underlying estimates made necessary by lack of precise data, make this a "tenuous estimate" as the authors admit. The estimate is based on the assumption that firewood consumption amounted to 25% to 50% of all wood produced outside of shifting cultivation. It is also assumed that biomass has a burning efficiency of 50%. Wong (1978) adopted a wood burning efficiency rate of 75%. See Seiler and Crutzen, 1980.

[48] In 1989, levels of ozone and acid rain pollution that were characterized as "high and normally associated with industrialization" were discovered over the forests of Central Africa, extending all the way from Zaire to the West coast. The pollution existed throughout the year and was "comparable to levels found in Europe and North America." The levels of acid were thought to be serious in the Ivory Coast, Gabon, Congo, and Zaire. The gases were believed to be caused by man-made fires (New York Times, June 19, 1989, 1).

that African savanna fires release three times more gases and particles into the air than all the fires of South America. He estimates that Africa contributes at least half of CO_2 emissions released by biomass burning or deforestation.

The reason for this is that while burning destroys more biomass per unit of land in rain forests, burning in dry savanna covers a larger area, is more frequent, and burns a larger volume of dry grass, which burns at a higher efficiency than moist vegetation. Once the forest is cleared and turned into grassland, it is then burned over and over again (New York Times June 19, 1989). Naturally, some of the carbon released is recycled through tree growth. However, the amount of carbon that can be thus recycled is limited by continuous burning, where trees are not allowed to fully recover.

The potential of biomass burning in raising greenhouse emissions has been absent in most studies. In particular, previous studies do not consider emissions from biomass burning in the household sector, where millions of small fires burn on daily basis in all of Africa. To the author's knowledge, this aspect of global warming has not been examined yet. It is assumed that emissions from these sources are recycled, but no quantitative evidence is usually offered.

Seiler and Crutzen assume a firewood burning efficiency of 90%, and estimate that 50% of all wood is used for cooking, but they do not calculate the amount of carbon released by households burning of biomass (1980, 229-31). Extrapolation from these estimates is extremely hazardous, but based on the share of Sub-Saharan Africa in global wood consumption, an estimate of 0.69 billion tons a year of emissions from biomass burned for energy, not in forest fires, can be guessed on the basis of Seiler and Crutzen's figures. These releases have to be netted against carbon absorbed either through natural tree growth or reforestation; the latter is quite limited.

As mentioned earlier in this Chapter, one of the important characteristics of energy use in Africa is the high level of reliance on charcoal. Charcoal, which is produced from the incomplete combustion of wood, is a carbon sink. In that capacity, it may be a modifying factor of carbon emissions, and so may hold some implications for global warming. On a world scale, the amount of carbon released from fires stored as charcoal is estimated at 1.1 billion tons annually, i.e., almost 30% of total gross carbon releases from fires (Ibid., 237).[49] At any rate, charcoal production in this region is not considered a significant factor in the global carbon cycle (Post 1992).

If in fact biomass burning turns out to be a

[49] Large scale charcoal production in Africa provides only a temporary sink for carbon emissions. Since charcoal is burnt again as fuel, gases are finally released.

significant source of global warming, this alters the balance between fuel wood consumption and agriculture as causes of global climate change. The former will assume higher importance. In agriculture, part of the carbon released is used again by growing trees during the process of photosynthesis. Hence the net result is mitigated. In the case of wood harvested for fuel wood consumption, unless the land is reforested, emissions from wood burning may contribute to carbon concentrations in the atmosphere. Moreover, wood burning releases other gases, notably methane and nitrous oxide.

Summary and Conclusions

1) This Chapter has reviewed three issues: biomass energy in less developed countries, its role in tropical deforestation, and the relation of all that to global warming. Biomass fuels are the dominant source of energy across poor countries, but they assume an exceptional importance in Sub-Saharan Africa. Except in Latin America, biomass consumption is dominated by households, but the role of traditional industry is expanding due to the unavailability of modern fuels resulting from foreign exchange shortage.

2) Tropical deforestation covers wide areas with highly differentiated scale and intensity. Statistics show that, with a few exceptions, the pace at which forests are

disappearing has accelerated since the late 1970s, mainly due to expansion of area under cultivation and to satisfy energy requirements of rapidly increasing populations. In Africa, the latter contributes to deforestation more significantly.

3) The process of forest depletion implies different cost-benefit ratios for different countries. Preliminary estimates for The Sudan indicate a net cost even without inclusion of all the negative impacts associated with forest destruction. Though individual households may be welfare maximizing, the destruction of agricultural productivity and reduction of revenue from tourism holds serious outcomes for the national economies of Sub-Saharan Africa.

4) The relation of forest resources to fuel wood prices has also been examined. It is suggested that demand and supply elasticities in the fuel wood market are low, therefore resulting in relatively small quantity adjustments. This shifts the burden of market adjustment to prices, which could imply that the progress of deforestation would be reflected more in price hikes than in quantity adjustments.

5) Global warming is a question still surrounded by many uncertainties and scientific disagreement. However, the prospect plus the uncertainty provides grounds for action. The contribution of Sub-Saharan Africa to global

greenhouse emissions from tropical deforestation at present stand at 20%, which is not insignificant. If other sources are confirmed, this contribution may rise. Any optimistic forecast of economic growth in the region will imply considerable increases in its emissions' levels because present releases are depressed by sluggish economic performance.

6) Fuel wood consumption holds implications for global warming- aside from deforestation, because of greenhouse emissions from wood burning. This may all be recycled in the overall carbon cycle, but the possibility requires further research. In the event of that possibility arising, current research shows that improved stoves hold significant potential for cutting greenhouse gas emissions through reducing both fuel wood consumption and emissions from wood burning.

The following chapter examines the implications of the introduction of improved stoves for the issues raised in this one.

CHAPTER 5

IMPROVED COOKSTOVES

This chapter examines the effect of improved stoves on deforestation within the theoretical framework of the market for fuel wood introduced in Chapter 4. The chapter is divided into three main sections. The first section surveys the experience of improved stove programs, with special emphasis on Sub-Saharan Africa and The Sudan. The survey incorporates matters of technology and design, dissemination of stoves, and the role of social and institutional factors in modifying welfare maximizing decisions concerning improved stoves. These issues are the second test of the hypothesis of the present study.

Section 2 discusses the environmental impact of improved stoves with respect to reducing deforestation and toxic fuel emissions. The final section analyses the effect that the introduction of improved stoves has on household's demand for fuel wood, as well as other variables in the fuel wood market, particularly prices. This provides the remaining test.

1. An Overview of Improved Stove Programs

Improved cooking stove programs are designed to serve a multitude of purposes ranging from raising income and conserving energy to reduction of health hazards and environmental pollution. The overwhelming majority of improved stoves are designed for household use, but some stoves designed for commercial use and relatively large scale operations have been introduced in some countries.[1] Most stoves introduced use firewood, but in Africa more charcoal-burning stoves are found.

Over a period of almost half a century a countless number of improved stoves - absorbing considerable resources - have been built, but there is little follow-up. Programs are usually sponsored by international development organizations, research institutes, and more recently, governments. Today stove programs exist in a large number of countries, but few have been carried out successfully. Nonetheless, a recent study evaluating stove programs in a number of countries considered its findings "encouraging news."[2]

The study found that dissemination of improved stoves has increased remarkably in the last decade. For example, the number of stoves built in Burkina Faso increased by almost 50 times from 4,000 to 200,000. The number of stoves rose from 6,000 to 180,000 in Kenya, and from 1,000 to

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[1] These have been introduced in Kenya and the Philippines. For other examples see Wood, 1985.

[2] The countries surveyed are Guatemala, India, Indonesia, Kenya, and Niger.

40,000 in Niger (FAO 1991, 48). The survey also confirmed evidence of fuel savings, though accuracy of measurement is still an issue. Savings in cooking time have also been observed. The following section gives a background picture of improved stove programs prior to delving into more specific issues.

1.1 The Experience of Improved Stove Programs

The first improved stove was introduced in India in 1947. It was an improved version of the traditional Indian Chula, made of clay and designed to burn all types of biomass fuels.[3] The objective of the stove was to reduce the risks of indoor air pollution by elimination of smoke. After further modifications on the Chula, the Raju Chula stove was introduced in 1953.[4] This was perhaps the first improved stove designed with the explicit objective of reducing fuel wood consumption to combat deforestation. It was estimated that it could annually save 20 million trees in India, and 80 million worldwide (Foley and Moss 1983, 103; Foley et al 1984, 59).[5]

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[3] Chula, sometimes Chulha, stands for stove in Hindu.

[4] Named after the designer of the stove, Dr S.P. Raju. The Raju campaign was known as "smokeless kitchens for the millions." The stove was also known as the HERL Chula because it was designed at the Hyderabad Engineering Research Laboratory. See Foley et al, 1984.

[5] Another early experiment with improved stoves took place in Indonesia. Working for FAO and the Swiss government, Hans Singer developed a stove known as " the Singer stove" that was popularized through training sessions. Unfortunately, no record of the stove is available today (Foley et al 1984, 60).

These early attempts did not survive, but they provided basis for later research and development when interest in this technology was revived in the 1970s. The decade of the 1980s witnessed the recognition and involvement of governments in improved stove programs. By 1983, it was estimated that over 100 stove programs were underway world-wide (Ibid., 62). Programs are concentrated in Africa and Asia, where reliance on biomass energy is greater than in Latin America.

In India, a wide variety of stoves are currently promoted. The most important model is Nada Chula, which was constructed by a woman in the village of Nada in Northern India in 1980. Being simple in design, the stove achieved wide acceptance. By 1985, over 3,000 stoves had been built. A survey undertaken in 1986 found that 84% of the stoves were in use. About 74% of users expressed satisfaction with their stoves because they saved fuel and cooking time, and reduced smoke, though these parameters were not rigorously measured (Sarin 1989, 24, 27). Another stove known as the ASTRA stove was developed in Southern India in 1981, but there is no follow-up on it (Foley et al 1984, 74).[6]

In 1985, the Indian government launched the National Cookstove Program after a strong positive response to a pilot project in 1983. The objective of this program was to

[6] The stove is known as the ASTRA stove in reference to the Center for the Application of Science to Rural Areas.

reduce fuel wood consumption, and hence deforestation in rural areas, create employment opportunities, and stimulate local crafts. Between 1983 and 1986, the government spent $15 million to install 3 million improved stoves. Follow-up showed that 50% of stove users surveyed indicated the stoves saved fuel, and reduced smoke, whereas improved stoves were reported to use more fuel than traditional ones by 16% of those interviewed (Garg 1989, 97, 100).

Improved stoves spread to other countries in Asia. In Sri Lanka, early trials were not successful, but in 1979 a stove was introduced to save fuel and reduce health risks as part of the Sarvodaya Shramandana rural development movement. The Sarvodaya mud stoves were socially accepted, and reported to achieve 20-25% fuel savings, but they were heavily subsidized (Amarasekera 1989, 118). Earlier on, ceramic charcoal stoves were promoted in urban areas to encourage consumption of fuel wood remaining as a by-product of land cleared for agriculture. By 1983, about 20,000 stoves had been sold, but only 4,000 families reported using any (Foley et al 1984, 71).

In China, both fuel wood and coal saving stoves are currently promoted. The stove project is embodied in the seventh Five Year Plan. Investment is undertaken by individuals with assistance from the government. Over 100 stove models had been developed to suit different local conditions. Between 1983-86, some 60 million households had installed improved stoves that reportedly used half as much fuel as traditional ones. In some cases the new stoves were reported to have created a surplus of wood and grass that was not utilized in a productive way. The program also had difficulties with publicity, and training (Wang and He 1989, 70).

Since 1981 several ceramic stoves based on the Indian Magan Chula have been developed in Khatmandu, Nepal, where pottery is an ancient tradition. Laboratory tests showed that fuel wood savings varied between 36% to 47%. The stoves had a lifetime of 2 years (Ranatunga and Shrestha 1989, 107, 109). In Indonesia, a stove program was introduced by a non-governmental organization (NGO) in 1979 with the objective of slowing deforestation. Later on, it was broadened to include reducing smoke and cooking time. Some 5,000 to 6,000 stoves were built, but most fell out of use (Foley et al 1984, 70). Currently stove programs exist in Bangladesh, Pakistan, Papua New Guinea, the Philippines, and Vietnam, but most are still in preliminary stages (Cáceres et al 1989).

Perhaps the most widely known improved stove is the Lorena stove.[7] This stove was developed for Guatemala by the Aprovecho Institute in Oregon, USA, in response to increased need for wood for construction following the 1976 earthquake. The project was launched by a Guatemalan NGO.

[7] The name is derived from the Spanish words Lodo (clay), and arena (sand).

The stove was made of mud and sand, and was based on the Indian Chula. It was claimed to save half to three quarters fuel wood compared to traditional stoves. By 1983, about 6,000 Lorena stoves had been built (Foley et al 1984, 64).

The Lorena stove suffered from a few drawbacks such as lack of durability and inability to provide space heat. Nevertheless, the overall experience was considered successful. The stove did save fuel, reduced smoke and risk of burns, and added an aesthetic look to kitchens. Lorena stoves were later introduced in Mexico, Ecuador, Jamaica, Honduras, and the Dominican Republic.[8] In fact, most improved stoves later introduced in other less developed countries, especially in West Africa, were based on modification of the Lorena stove concept.

Other stove programs in Latin America include the Ceta program in Guatemala, and relatively small projects in Brazil and Nicaragua.[9] The Ceta stove is part of a forestry initiative. In return for improved stoves, each family agrees to plant and maintain ten small trees provided by the government. A 1985 survey showed that Ceta stoves had been well accepted. The Brazilian program was launched in 1983 in the Northern state of Paraiba. Slightly over 400

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[8] These are mostly small programs of a few hundred stoves.

[9] The Central American Research Institute for Industry (ICAITI) introduced a pre-fabricated ceramic stove in 1984. By 1986, over 4,000 stoves were reportedly installed, 3,500 of them in Guatemala. The stoves, which were believed to achieve 34% fuel savings, were mostly sold through the ceramicists themselves (Cáceres 1989, 92-93).

stoves have been distributed thus far. The stoves indicated fuel savings of 30% (Pinto 1989, 64).

In Africa, the experience with improved stoves dates back to the early 1960s, when the Ghanaian Department of Social Welfare and Community Development introduced a smokeless, clay oven in several villages in Ghana. Since then almost every country in the region has developed its own stove project.[10] In 1977, a study found that the Ghanaian stoves had fallen out of use. Users complained that they did not reduce fuel consumption, they used large pieces of wood that required long trips to obtain, and that the pot holes in the stoves did not fit the utensils used in the village (Foley et al 1984).

The longest running stove project in Africa is the Senegalese program launched in 1980 by the Aprovecho Institute, and the US Peace Corps, with a grant from USAID.[11] The Ban Ak Suuf stove, which was adapted from the Lorena stove, indicated fuel savings of 40% (Ulinski 1981, 247).[12] The stove was mainly distributed in rural areas. By 1982, about 5,000 stoves had been built. A 1983 survey showed that 65% of households were using their stoves one year after acquiring them. A metal charcoal stove was

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[10] For other improved stoves, or stove programs in Africa that are not discussed here. See Norman, 1981; Hill et al, 1986; SERC, 1988; and Cáceres et al, 1989.

[11] Several other organizations were also involved in the program, which also included improvement of charcoal production efficiency.

[12] The name stands for clay (ban) and sand (suuf) from the Wolof West African language.

introduced in urban areas in 1982 (Foley et al 1984, 65-67). Laboratory tests showed that its fuel savings varied between 15% and 33%. In household conditions the stove could achieve a maximum of 25% fuel wood savings (Gueye and Madon 1983, 635, 632).

Burkina Faso was the first country in Africa to undertake large scale distribution of improved stoves. In 1975, a stove known as the Nouna, with fuel savings of 15% to 23%, was introduced.[13] The stove was made of fired bricks and cement. The cement had to be imported, resulting in a subsidized price of $20 per stove (Foley et al 1984, 66). Since 1979, more than five stove models have been developed. Portable stoves introduced after 1982 fared better than the Nouna because they were cheaper and realized fuel savings of about 40%. Altogether, it is estimated that by 1987, over 36,000 stoves had been disseminated commercially in Burkina Faso (Sawadogo 1989, 6-7).

The stove program in Niger was initiated by the Women Association of Niger, and US Church World Service in 1980.[14] About 315 institutional stoves were built for use

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[13] Nouna is a town in Burkina Faso.

[14] Another improved stove project was initiated in Niger in 1985 by the World Bank, United Nations Development Program (UNDP), and the German Agency for Technological Cooperation (GTZ). By 1986, the program had distributed 12,500 stoves and sold another 17,600 in the market. Evaluations indicated that 83% of users experienced fuel savings. See Mildeberger and Klingshirn, 1989, 111; and Mounkaila, 1989.

in urban areas.[15] Lorena-type stoves, made of banco or cement, were also introduced.[16] They were heavily subsidized to sell at $6.00 each (Foley et al 1984, 72. Evaluation of the program in 1982 revealed that the stoves consumed 14% less fuel than traditional ones (Massé 1985, 25).[17] Users were overwhelmingly satisfied with their stoves though fuel savings were not their primary concern. Many of the stoves initially distributed were not used. Little follow up has been undertaken since (Mounkaila 1989).

The most successful improved stove program is by far the Kenyan one. A number of local NGOs and international aid organizations, as well as the government, have been involved in stove development since 1984. This has resulted in a variety of stoves, but the most successful effort is the Kenya Ceramic Jiko stove (KCJ) sponsored by the USAID Kenya Renewable Energy Development Program (KREDP).[18]

The project was preceded by considerable research in universities and research centers around the country and abroad. Several models were developed. The UN Children's Fund (UNICEF) had designed an all-metal stove named Umeme

[15] Institutional stoves are fixed, immobile stoves built insitu. They are usually intended for commercial and other large scale operations.

[16] Banco is a material similar to adobe. It is the local building material used in Niger.

[17] The stoves were in bad condition, and were poorly maintained, which might partly explain the low fuel savings.

[18] Jiko is the Swahili word for stove.

in 1981.[19] The stove used considerably less fuel than traditional ones, but it was not selected due to its high price and complex design. A metal charcoal stove adapted from the Thai bucket was selected instead. The design saved 33-55% fuel (Jones et al 1989, 22).

The size of the Kenyan stove market in 1985 was estimated at 460,500 stoves each year, with almost 60% of that located in urban areas. By 1990, the number of stoves was expected to reach 596,000, with an urban share of 66.6% (Ibid., 15). The decision was made to target urban areas. By 1985, around 84,000 stoves were reportedly disseminated. Almost 6% of Kenya's urban households had improved stoves by 1986 (Hyman 1986, 151, 152). The program is self-sustaining, and is currently producing 180,000 stoves annually (FAO 1991, 48).

The Kenyan project had clear goals. These were defined as: simplicity in design, low price, superior quality, provision of significant financial benefits to both producers and users, accommodation of cooking methods and eating habits, and reliance on local material and skills. Concentrating on urban markets, the project was able to utilize traditional manufacturers in the informal sector to displace traditional stoves. The program is said to have created a new cadre of entrepreneurs, encouraged recycling, raised employment, and opened up lines of communication

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[19] Umeme means lightening in Swahili.

between the informal sector, research centers, and policy makers (Namuye 1989). The KCJ has also been introduced in Rwanda.

In the mean time, several other stoves were developed by other organizations in Kenya. The UNICEF continued to process its Umeme stove.[20] By 1985, over 4,000 stoves had been produced (Hyman 1986, 152). In 1983, the German Agency for Technological Cooperation (GTZ), working with a leading Kenyan women's group, developed a ceramic, no chimney stove for rural areas known as Maendeleo. About 10,000 stoves have reportedly been distributed. A 1986 survey showed that most of the stoves were still used in the proper manner, and that users were satisfied (Njorge 1989, 101; Mildeberger and Klingshirn 1989).[21]

Several other countries in Africa have improved stove initiatives or programs underway. In Zimbabwe, the government introduced a fired-brick, three-pot-hole stove with a chimney to conserve wood in rural areas. Ethiopia launched a stove program following the 1983 UNDP/World Bank energy sector study.[22] In 1988, the program was still in

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[20] A version of Umeme known as Haraka stove was developed in 1986 (Hyman 1986).

[21] Other stove efforts in Kenya include CARE international Relief Organization ceramic stove project. The Bellerive Foundation introduced a metal charcoal stove (Micuta) in 1980. It was extremely expensive (eight times the price of traditional stoves). There is no follow-up. Bellerive is also engaged in developing large scale, institutional stoves for schools and hospitals. See Hyman, 1986; and Njorge, 1989.

[22] In 1980, the Basic Technology Center (BTC) in Ethiopia, established with assistance from the UNICEF, had already been developing charcoal and wood stoves called the Gulicha stoves, with fuel efficiency more than double that of the open fire. See Mekuria, 1985, 169.

its preliminary stages, but showed promise. There are also improved stove programs in Botswana, Burundi, Gambia, Lesotho, Liberia, Mali, and Zimbabwe (USAID 1981, Caceres 1989).

1.2 Improved Stoves in The Sudan

In The Sudan, a number of improved stoves have been developed. Research is carried out by the Energy Research Council (SERC) and the Ministry of Energy, in collaboration with a number of agencies including USAID, FAO, UNICEF, and CARE International Relief Organization. Most stoves use charcoal, being the dominant source of energy for urban households in The Sudan. The major stoves introduced to date are:

a) The Ahfad charcoal stove. This is the first improved stove in The Sudan. It was designed at the University of Khartoum in collaboration with Ahfad College in 1981, and was based on minor modification of the traditional charcoal stove. Its objectives were to minimize fuel waste, and utilize local materials. The stove was made of recycled metal sheets. It reportedly cut fuel requirements by 7%.

Field tests showed that the stove also reduced cooking time by one third. The new stove cost more than the traditional one, but it was claimed to be more durable and less expensive to maintain. It was estimated that the Ahfad stove would save 17,916 tons of wood per year, assuming a charcoal conversion efficiency of 15%, which is the rate prevalent in The Sudan (El Sayed and Amin 1981, 97). No record of the scale of distribution is available.

b) Canoun El Duga (CED).[23] This is considered the first serious attempt at producing improved stoves in The Sudan (El Faki 1988). It was introduced in 1984 by the Energy Research Council, under the Sudan Renewable Energy Project (SREP) II, sponsored by USAID. It was designed to use charcoal fines. The stove was estimated to use 43% less charcoal, and to be three times more durable than traditional stoves. These aspects were thought to compensate for the higher cost of the stove (Whitney et al 1987, 334).

Production of the CED stove was discontinued in 1988 for a number of reasons, including high cost and scarcity of material. The stove was made of new - not recycled - metal sheets, its high cost did not allow any profit margin, hence the project failed to initiate wide interest among small producers. Besides, the rate of turn-over among artisans in the informal sector resulted in erratic production rates. In addition, the economic rationale for the project was based on the assumption that, as a by-

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[23] Canoun is the Sudanese word for stove. El Duga means charcoal fines. These are generated during the production of charcoal. Earl (1984, 12) estimated that at least 20% of the wood remains at the kiln site after production is completed. Fines also accumulate during transportation of charcoal, which is prone to breakage during handling.

product, charcoal fines would be available at no cost to users. That proved to be untrue. It is estimated that altogether 8,876 stoves had been produced by 1987 (El Faki 1988, 44).

c) Canoun El Surour (CES).[24] This modified version of the Kenyan Jiko stove was introduced in Kordofan region by CARE. The stove is made by local tinsmiths out of used vegetable oil cans donated by the US for drought victims. It has an hourglass design, where charcoal is burned in the lower chamber. Heat is transferred into the upper chamber, and the pot is placed on top of a ceramic liner. This is believed to be the largest appliance manufacturing project in The Sudan. More than 22,000 stoves are reportedly in use currently. It is claimed that the stove uses 50% less fuel than traditional designs. This is estimated to save about 59,400 tons of wood annually (Wirt 1991, 108-9).

CARE later decided that it was more effective to disseminate the stoves in urban markets, where large risk-taking producers can be involved. The CES stove was introduced in Khartoum in 1987. CARE claims to have sold over 10,000 stoves since then, and that demand is higher than had been anticipated (Jones et al 1989, 97). The stove is produced by artisans in the informal sector and the only obstacle is believed to be limited production capacity.

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[24] This translates as the pleasurable stove.

d) Canoun El Jadid (CEJ).[25] This stove has been introduced in Southern Sudan. It is a modified version of the UNICEF Umeme stove. The stove is manufactured of used oil drums by metal workers in the city of Juba. It has insulated walls filled with earth to reduce heat loss. The cooking pot is placed inside the firebox to increase the amount of heat it receives. The stove uses twice as much material as traditional ones, hence it costs more. Project officials claim that it saves up to 60% fuel (Albee 1984, 13). The scale of dissemination has not been reported.

e) The Kisra stove.[26] This stove was developed by the Forests National Corporation in collaboration with FAO. It is made of clay and fired bricks, and burns fuel wood or crop residues. It was designed for self-construction. The stove was disseminated in rural areas and refugee camps. It reportedly achieved 50% improvement over traditional stoves in its use of fuel (FNC).[27] FAO is also promoting another improved stove modelled after the Thai bucket through the same producer working with CARE.

The CES and the Ahfad stoves are used in the present study as basis for evaluation of improved stoves in

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[25] In Arabic that means the new stove.

[26] Kisra is the traditional Sudanese bread. It is baked on a large grill over a four stone fire, and consumes considerable amounts of fuel.

[27] The Forests National Corporation has developed three other stoves. One is made of a clay/manure mix, designed to burn all types of traditional fuels. The two other stoves are made of metal, and burn charcoal. There is no record of commercial dissemination of any of these stoves.

general. The Ahfad stove is the only one for which laboratory testing results are available. This is an important consideration since claims of fuel savings are rarely based on rigorous testing. The Ahfad's modest fuel savings (7%) make it a good candidate for a lower bound case. The CES stove is selected because it is currently produced on a large scale. Even though the claim of 50% fuel savings is questionable, realistically this may be the maximum improvement stoves can achieve. Accordingly, the Ahfad and the CES stoves are used as an envelope for fuel savings by improved stoves.

This survey of improved stove programs across less developed countries indicates a growing number of programs, stove models, and institutional involvement. Nonetheless, improved stoves have not yet become a feature of life in most places. Only a few projects have achieved commercial success. In many cases programs do not stay in place long enough to observe any impact on the local economy, fuel wood consumption, or users' behavior. In others, the large number of stove models introduced may slow down the process of feedbacks concerning stoves' effectiveness.

Early stove programs focused on rural areas as part of the appropriate technology paradigm stressing self reliance, with improvement of living standards and the quality of life being a major feature of that stage. Overtime, slowing deforestation gained more prominence as one of the objectives of improved stoves. More recently attention has shifted toward urban areas in recognition of the role they play in forest depletion through concentrated fuel wood consumption, and use of charcoal. This latter stage is characterized by reliance on market channels. The success of this strategy is evidenced by the Kenyan program.

The remainder of this chapter discusses the determinants of the impact of improved stoves on forest resources. These are: improvement in the efficiency of fuel use, large scale adoption of stoves, and the specific parameters of the fuel wood market, particularly on the demand side.

1.3 Stove Design, Efficiency, and Fuel Savings

Improved stoves are intended to fulfill a number of economic, social, and environmental functions. Stoves are mainly intended to raise income, but they are also desired to reduce the drudgery, and may be even improve the aesthetics of traditional cooking. The benefits of improved stoves to the environment include containing deforestation, reducing toxic emissions from burning fuels, and reducing the risk of burns and fires. This multiplicity of goals makes stove design a complicated matter; achieving one goal may conflict with others. All this is thrown against a cost constraint since the affordability of stoves is a crucial factor.

Traditional stoves encompass a wide variety of designs and features. Portable charcoal metal stoves are common in urban Africa.[28] In Asia, the most popular stove is the Chula: a ceramic, wood-burning, sometimes portable stove, known by different names in different countries. Whereas fixed stoves are common in Latin America. The Chula equivalent here is the Poyo Campesino, made of a clay platform with a chimney and brick enclosures for fire on top. Pots are placed on metal plates on top of the enclosures.[29]

So far the technical modifications on traditional designs have been centered around: a) partially enclosing the fire to improve combustion; b) providing a chimney to reduce smoke; and c) introducing a damper to control heat to desired levels (Clarke 1985). These alterations have been reflected in the choice of construction material, size, number of pot holes, portability, and a number of other stove characteristics. It is essential to bear in mind that fuel saving is not always the most important objective.

Construction material is an area over which much

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[28] In The Sudan, the traditional stove is rectangular in shape, mostly designed for one pot, but there are also big ones where several pots can be placed. The stove has a grate at the top where the pot is seated, and a side door through which the ashes can be removed.

[29] Fixed stoves are also found in China, Egypt, India, Nepal, and in West Africa.

controversy has taken place, for instance the choice between local materials and pre-fabrication, and between clay and metal. All first generation improved stoves were massive, oven-types, with multiple pot holes and chimneys, and were made of mud or clay.[30] Clay and mud have a few disadvantages. They are sensitive to the mixing formula. Too much clay causes cracking, while crumbling results from the excess of sand. This was experienced with the Ban Ak Suuf stove in Senegal (Ulinski 1981).

Improved metal stoves are a more recent development brought about by the spread of stove programs in Africa. In early programs, metal was considered undesirable because it resulted in loss of heat by radiation from the body of the stove, in addition to the higher risk of burns. However, recently it has been realized that heavy mud or ceramic stoves absorb a great deal of heat in their mass. It has been suggested that the heat can be recovered for later use, but evidence show that only 2% of that heat can be recovered (Prasad 1985, 67).

The number of pot holes is another issue in stove design. Multiple pot holes are desirable to utilize the total amount of heat generated, thereby raising the efficiency of the overall system. The problem is that most improved stove designs do not allow simultaneous use of the

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[30] The Lorena stove had three pot holes, and was built by adding thick layers of the Lorena material. It took three days to construct. Other examples are the Indian Chula and the Ghanaian oven.

pot holes, thereby defeating that purpose.[31] The portability of stoves is also another consideration in stove design. The lightness and flexibility of the single-pot-hole stove make it more acceptable, especially in Africa where cooking is extremely mobile.

It has already been stated that reduction in fuel consumption through improving the efficiency with which stoves burn fuel is one of the most important features of improved stoves because of the expected impact on deforestation.[32] Traditional stoves are believed to be grossly wasteful in their use of fuel. It is often claimed that fuel efficiency varies from 3-5% for the open fire, to 10-20% for stoves and ovens (Club du Sahel 1978, 49; Cecelski 1983, 23; Foley et al 1984, 11). In The Sudan, wood stoves are estimated to have an efficiency of 6% (Whitney 1981, 15). While the efficiency of charcoal stoves is estimated to be between 16% (Ibid.), and 18% (El Sayed and Amin 1981, 96).

Accordingly, it is often taken as given that improved stoves could easily cut fuel consumption by half (Ulinski 1981, Albee 1984, Wirt 1991). This has proved to be not so simple. Laboratory performance is rarely matched in real

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[31] Most early designs were adapted from old European stoves, where the second pot hole was used for water heating. Thus, "fuel economy has been achieved by producing hot water as a by-product," something for which there is no overriding need in tropical climates (Prasad 1985, 65).

[32] The term fuel efficiency in the literature is used to indicate the percentage of energy generated by fuel that is actually used in cooking a certain dish. Thus, a 50% efficiency means that half the heat generated is used. The remainder is usually lost for any one of various factors, e.g., radiation or draught.

household conditions. Efficiency is a relative concept influenced by a number of variables, including wood moisture content, fuel density, draught, power output, and even the type of utensils used for cooking. Technical efficiency refers to the ability of a stove to minimize the input of fuel relative to output. As such, it is independent of economic considerations.

Fuel savings refer to the ability of a stove to accomplish the same task, e.g., cooking a certain dish or meal within the household environment, using less fuel. This led some to argue that fuel economy rather than efficiency per se should be the criterion for evaluation of stoves' performance in relation to fuel wood consumption, and hence deforestation (Prasad 1985). Fuel economy is determined by fuel efficiency, in relation to power output, and by the time required for cooking.

It is hard to obtain reliable evidence of the often claimed 50% fuel savings because little testing is undertaken. Most surveyors simply ask users how much fuel they consumed before and after using improved stoves (Ulinski 1981, Jones et al 1989). Actual measurement is almost never undertaken. Consequently, testing results show wide variation in fuel savings, and often numerous results are reported for the same stove.[33] Some stoves showed savings of up to 60% (Ulinski 1981, 246; Wood 1981, 210).

[33] Four different quotations for the Kenyan Jiko stove can be found.

In other cases, improved models consumed considerably more fuel than even the open fire. Tests in Fiji, Indonesia, Nepal, Niger, and Sri Lanka indicated similar outcomes (Foley et al 1984).

Stoves' testing procedures lack standardization, which results in the discrepancies and conflicting evidence cited above. VITA (1983) proposed international testing standards to facilitate comparison between different models, but that has not been achieved yet.[34] Recently it has been suggested that the fuel saving potential of improved stoves may have been exaggerated. Most estimates of traditional stoves' efficiency have no clear evidence or basis. Moreover, it is now believed that the methodology underlying early tests of stoves' efficiency is faulty (Gill 1987).

To summarize, improved stoves do save fuel, but the claim of substantial fuel savings still begs serious validation. The evidence is sketchy and sometimes questionable. Failure to realize these savings stems from factors not always related to stove design. This is an important issue because even though technical fuel efficiency is the first step in generating a significant impact on fuel wood consumption, it is the overall

[34] The procedure suggested involves three tests. The first is the boiling water test: a simple, preliminary indicator of efficiency, measuring the amount of fuel and time it takes to bring a certain volume of water to the boiling point. Dutt (1978c) considered this test a confusion between efficiency and heating rate. The second test is the controlled cooking test, where a stove's performance in cooking actual meals is tested. The third test measures performance in kitchen conditions (VITA 1983). This usually involves more than one family for comparison. These tests overlook distortions in household's attitudes caused by eagerness to impress or to please the research team.

consumption of fuel and not consumption per stove that is critical in relation to deforestation. Overall fuel wood consumption is determined by economic parameters discussed later in this Chapter, but first, the important issue of wide scale dissemination is examined.

1.4 The Dissemination of Improved Stoves

It goes without saying that regardless of fuel efficiency or savings, improved stoves will not yield any tangible results until they are widely adopted. The ideal penetration rate is 100%; that is when stoves are used by all wood fuel users to cook all meals. Very few stove models have achieved large scale dissemination so far. With a few exceptions, dissemination approaches to improved stoves have been of technology push rather than technology pull.

Technology push exists when the introduction of a new device is determined at the macro-level, as part of a national policy (Joseph and Hassrick 1984). For instance, improved stoves are pushed forth as a means of containing deforestation, which is considered a national concern. At the micro or local level individuals or households may lack any perception of a problem, hence creation of an effective demand for the new technology is a difficult task.

On the other hand, adoption of improved stoves is relatively smooth and expeditious if there is technology pull, i.e., a specific need for improved stoves is present at the user level. That need not be fuel savings. Indeed, it almost never is. Because of the externality of deforestation, saving fuel wood is not of the highest priority to users. From the experience of stove projects it appears that stoves have not been able to address the most urgent needs of local populations.

The Lorena stove had a high acceptance rate, but the main reason behind that was smoke reduction.[35] Only 6% of families using the Lorena stove indicated that it used half the amount of fuel wood used before (Shaller 1981, 31). Space heating and flexibility in pot sizes were more important considerations to users than fuel savings. Users also liked the Lorena stove for its cleanliness. Some appreciated the decorated appearance of the stove (Ibid., Cáceres et al 1989).

Creating a technology pull then does not have to be determined by macro objectives. Policy may be more effective if these are realized through other goals presenting a more immediate concern to users. Stove programs may target all benefits that can be delivered at the micro level if effective demand or technology pull is to be created and sustained, e.g., employment, convenience

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[35] In other areas that may not pose a problem. Smoke is desired for thatched huts to kill bugs and keep the thatch waterproof, and to drive away wild animals, or for food storage.

in cooking, health benefits, or time savings.[36] Howes (1985) suggests that dissemination may be more successful if stoves are packaged within a broader objective such as women development or health improvement.[37]

Moreover, the appliances that are to be replaced present an important issue. In this respect, there are two types of new technology: one that introduces a whole new concept, e.g., watches; and one that performs a function of a pre-existing technology in a better way, such as high yielding variety seeds (Ibid.) The first type faces minimal or no competition. The task of improved stoves is challenging because they must displace a technology that mostly works well; users have little reason to switch to a new one. In Kenya, the Jiko stove achieved wide dissemination because there was a conscious concerted effort at displacing traditional stoves.

Traditional stoves are multi-functional devices, unlike the electric or gas stove. The open fire is rudimentary, but it is extremely versatile. It uses a variety of fuels, knows no spacial limitations, and can be

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[36] To the extent that an improved stove does not entail considerable modification on an existing design, or simply involves the same producers, the impact on employment will be negligible. In Kenya, it takes about the same amount of time and skill to manufacture or assemble an improved Jiko as a traditional one (Hyman 1986). However, since the new stove requires a new part, the ceramic liner, the project has given rise to a whole new branch of industry to manufacture that part. It is estimated that 1,000 artisans are involved in the production of improved Jikos (Namuye 1989, 42). On the other hand, the initial reduction of fuel wood purchases could result in loss of employment in sectors engaged in fuel wood production, e.g., the charcoal industry.

[37] This has frequently been tried. As the previous survey of stove programs reflects, even the names chosen for improved stoves are carefully selected to convey some kind of a message.

adjusted to hold different pot sizes. Besides, it provides a spectrum of other services ranging from space heat to social functions. In less developed societies, there is a tendency for tools or devices to be all-encompassing, whereas economic development involves a higher degree of specialization and product differentiation. Improved stoves will not likely replace every aspect of traditional ones, therefore, they may have to be accompanied by a set of complementary products to fill that gap.

In any event, irrespective of technology push or pull, large scale distribution of stoves requires careful examination of economic and demographic variables, such as population, prices, income, and consumption patterns. This is then followed by sensitization: a process involving familiarization with the appliance to remove misconceptions or apprehensions associated with it. This phase usually includes training sessions, using different media. Sensitization was carried out successfully by the World Bank in Niger. Stoves were sold immediately after demonstration sessions. In the first two years of the project 40,600 stoves were distributed (Mildeberger and Klingshirn 1989, 111).

Wide scale dissemination, which has for a long time been the single preoccupation of stove program officials, is a slow and time consuming process (Clarke 1985). In Latin America, clay stoves were widely accepted, but dissemination was slow due to lack of official support (Cáceres et al 1989). In Kenya, the Jiko stove realized a diffusion rate of 17% in Nairobi, but it took diligent campaigning (Namuye 1989, 44). Still, over 27% of residents never heard of the new stove (Ibid., 42).[38]

Three dissemination strategies can be identified: the market approach, the subsidy approach, and the appropriate technology approach. The first strategy relies on the market, using centralized large scale operations. It, therefore, targets upper-income urban users. This strategy performs well if the new stove is sufficiently competitive to stand on its own, i.e., without subsidy (Foley and Moss 1983). This strategy does not involve a social cost since users bear the full cost of the stove (Howes 1985). In the Kenyan program competition ensured the self-sustainability of the project.

The second dissemination strategy involves provision of subsidies to ensure greater access to stoves, especially by lower income groups. This strategy entails a social cost in the form of the subsidy, which is somewhat risky. The larger the subsidy, the smaller the chance of success. The size of the subsidy usually indicates the magnitude of

38 The concept of half-life is sometimes borrowed to illustrate the scale of dissemination required. The half-life of a stove is said to be the length of time it takes for it to wear out. Depending on a stove's half-life, at any point in time only a certain maximum number of stoves will be in use (Wood 1982). For instance, the observed half-life for stoves promoted in West Africa is one to two years. Thus, if a program builds 1,000 stoves a year, with one year half-life, no more than 1,999 will be in use at any one time. This implies that dissemination has to be progressive, i.e., the number of stoves diffused must continuously increase.

large scale economies required for a product to become competitive. At best, stoves will have to achieve considerable penetration rates before the subsidy can be removed, which may take a long time. The subsidy for one of the stoves introduced in Niger exceeded 75% (the price had to be reduced from $36 to $7-10 (Massé 1985, 25). It is reported that the high subsidy restricted competition.

The final approach to dissemination is the appropriate technology approach, which characterized the early years of improved stove programs. As is well known, this concept emphasizes rural development through technology deemed "appropriate" for the local environment. Under this method, villagers are trained to build their own stoves. From a decentralized decision making perspective this approach is plausible because it provides local communities with skills of survival and ability to adapt the technology to their own parameters. However, unless work in the early stages of programs is strong, this strategy runs into quality control problems. This was experienced in the Lorena stove program in Guatemala.

The choice of a dissemination strategy is critical because this process is not independent of the other determinants of the efficacy of improved stoves. For instance, when considering deforestation, the market approach seems more plausible because it targets urban areas; largely blamed for severe pressure on wood resources

(FAO 1991). As pointed out in Chapter 4, the pattern of fuel wood production in rural areas is less damaging than it is in urban areas.

Dissemination then is not simply a matter of market surveys and maximization of the number of stoves distributed, although that is an essential part of the process. The fundamental question of the place of a new technology within a community, and its relation to pre-existing appliances it is intended to replace must be addressed early on. Social factors play an important role in this context. These are taken up in the following section.

1.5 Social Dimensions

Dissemination of improved stoves is a sensitive matter because it involves penetration of social structures, habits, and household dynamics. This is important because the success of a new technology is conditioned by existing social biases and or dichotomies. With regard to the issue at hand, social factors are relevant insofar as they impose constraints on households' preference functions regarding fuel wood consumption, and substitution between new and old stoves within their commodity bundle.

Social biases influence the effectiveness of dissemination policies when certain segments of potential stove users are excluded. The most common dichotomies are along gender, income, or urban habitation. Decisions concerning household food supplies and eating habits, e.g., cooking and fuel wood gathering, are mostly taken by women, while men control budgets. Yet policies, deliberately or inadvertently, often exclude women. In Guatemala, it is reported that female participation in the Lorena stove building would have considerably improved the stove's performance.

The rich-versus-poor bias also influences access to improved stoves. In Kenya, the Jiko stove was purchased mostly by middle to high income families because it cost 3 to 5 times the traditional one (Namuye 1989, 43). Some households acquired the stove as a status symbol, and never used it. In Niger, institutional stoves were purchased by home owners since those who rented faced the possibility of frequent moving. Renters represented more than 50% of the urban population (Massé 1985, 25).

From a microeconomic perspective, social factors are important for the crucial question of how much adjustment in tastes and preferences improved stoves will entail. The influence of these factors is reflected in the observation that users invariably adapt the stoves to their needs. For example, people never used all pot holes in the Lorena stove. Instead, they used the firebox to cook a single dish more rapidly. Sometimes they built fires around the pots to heat them faster. Stoves that involved minor modifications in design such as the Kenyan Jiko, were more successful than those introducing several new parameters.

Social factors are often treated as superfluous ceremonialism, or as exogenous isolated phenomena. But these factors are more crucial than is usually thought. To illustrate, in Africa, women cook while sitting down on low stools. The Ghanaian oven was abandoned in part due to the fact that it was too high to allow stirring of the local porridge that required extended cooking. This brings about the issue of time allocation. Some improved stoves are designed to cut the time required for cooking, but the household's objective function may not always include time minimization. In many places food preparation is a social activity. The physical and spacial structure of the cooking area and appliances allows the activity of socializing and passing time.[39]

Within the lifetime of a certain stove, preferences may be treated as exogenous, but given time, these are adaptable. In the urban areas of poor countries, particularly where women work outside the home, the traditional style of cooking is limited to not-so-frequent social occasions. Historically, when income earning activities necessitated adjustment in life style, adaptation of tastes has been smoother. Accordingly,

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[39] In Africa, cooking involves a number of participants, and takes considerable length of time, which is not always a primary concern. Traditional cooking generally takes about 5 hours. The same was observed in other areas, e.g. Nepal (Cáceres et al 1989).

selling time-saving stoves may be more successful in urban areas. However, if firewood becomes too demanding in terms of the time required for collection, rural areas may become just as attractive.

Generally speaking, as part of the factors underlying every consumer's commodity basket, social factors cannot be dismissed as exogenous constraints. This is even more so in the case of improved stove programs, which are by definition designed to alter this basket through the introduction of a new product. Preferences adapt when, at the margin the benefits from improved stoves compensate for the inconveniences introduced by adaptation.

1.6 Institutional Barriers

The present study recognizes the role of market forces in adjustment of economic variables as is well established in the literature. In the present context, this refers to the necessary adjustments by stove users and producers. However, in practice, these adjustments can be modified by the institutional framework within which transactions take place.[40] Accordingly, institutional factors are analyzed to discern the nature of the constraints they place on welfare maximizing behavior by stove users and producers. The

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40 The word "institutional" is used here along the lines of the neo-institutional literature to refer to the non-market environment, which includes political, legal, and policy structures or bodies in general (Lance and North 1971, Williamson and Winter 1991). This is to be distinguished from variables of an institutional nature within the classical institutional paradigm that establishes a dichotomy between technological or instrumental factors on the one hand, and institutional or ceremonial factors on the other. See Veblen, 1919; and Ayres, 1962.

institutional framework surrounding improved stove programs includes government, donor nations and aid organizations, research institutes, and private enterprise.

Government has the most visible role in terms of facilitating or obstructing the operation of stove programs. This role is partly manifested in the form of legislation, taxation, or bureaucratic control, which all result in standard distortions of market processes abundantly treated in the literature. The government's capacity as an institutional barrier arises from political decisions affecting stove programs. This is important in the light of the fact that most poor countries lack the democratic process to exercise public choice decisions. Fortunately, the second generation of improved stoves witnessed the positive involvement of governments, e.g., in India, Kenya, and China, in stove programs.

In The Sudan, the most important institutional constraint on adjustment in fuel wood markets is the civil war in the Southern region, precluding use of forest resources there. Also, frequent government changes prevent continuity in decision making. Nonetheless, political volatility actually works in favor of stove programs because they are implemented with little or no government involvement. In contrast, policy measures such as reforestation are administered through government departments, which renders them vulnerable to bureaucratic control or frequent policy fluctuation. Improved stoves offer a higher degree of insulation from political factors.

Aid organizations and donor nations have their own agenda and timetables, exerting a great deal of influence through the control of finance. The constraints imposed by these agents on maximizing decisions of stoves' users and or producers are manifested in conditions imposed on different aspects of funds dispersal, such as location of stove programs, or stove design. Market decisions are also influenced by the political climate between these agents and governments in the countries where they operate, or by rivalry between different organizations functioning in the same country.[41]

Academic institutions and research centers are the laboratories where improved stoves are developed, and insofar as they understand the social parameters within which they operate, the outcome can be positive. But tensions may arise between research institutions and other parties that may ultimately be reflected in a higher cost of improved stoves. For example, laboratories may wish to set their own parameters regarding research facilities.[42]

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[41] Massé (1985) suggested that international support and finance may not always be desirable because it creates structures with tendency to persist even after the need for them has passed. But this is true of domestic structures as well. At any rate, it is important to take an inventory of local resources before setting up new apparatuses in order to avoid duplication of efforts.

[42] Jones et al (1989) emphasized regional coordination in the technical arena to economize on resources. For example, there is no need for each country to have a state-of-the-art research facility of its own. But, this may be perceived by local research institutes as limiting of their role. In the case of the USAID program in Africa, this issue was finally resolved by the establishment of the Regional Improved Stoves Program for Eastern, Central, and Southern Africa.

The private sector, in both its formal and informal configurations, exerts influence through control of production and manufacturing resources and expertise. As part of the market process, this sector is driven by profit incentives, thus its motivations are clear and can be readily parametrized. There is little ambiguity concerning its role. Early stove programs ignored private industry. The importance of this sector was demonstrated in the Kenyan Jiko stove program, where its role was instrumental in the success of the project.

NGOs have been very useful in coordination of stove programs, though this is not a simple task. Each party involved has two roles: a perceived role and a realized one. The first reflects an institution's own agenda and its role as seen by other parties. The realized role emerges from the interaction of the different parties. Some degree of conversion in perceived roles by all parties must be attained. The higher that convergence is, the stronger is the realized role, and the more successful is a stove program.

On the whole, institutional factors can greatly influence improved stove programs, especially where the latter is driven by political decisions. When the bulk of funds are donated by other nations, conditions stipulated by donors may distort efficient resource allocation. Political factors such as instability and lack of continuity in decision making can also disrupt stove programs. Nevertheless, when considering all policies designed to arrest deforestation, institutional factors are likely to exert greater influence on the outcome of measures that rely on macroeconomic implementation. Large scale reforestation is the clearest example.

2. The Environmental Effects of Improved Stoves

The environmental benefits of improved stoves can be summarized in four main areas: 1) reduced consumption of fuel wood, hence, slowing deforestation; 2) cutting the level of emissions of greenhouse gases to the atmosphere so as to mitigate factors contributing to global warming; 3) reduced emissions of carbon and other toxic gases, thereby alleviating the health effects of indoor air pollution; and finally, 4) reduction of the risk or incidence of burns and fires.

To the extent that deforestation is caused by fuel wood consumption, the available evidence, if sketchy, indicates that improved stoves will be effective in two related situations. The first is in urban areas, where consumption of fuel wood poses intensified pressure on forests and local ecosystems. Also, there is greater opportunity for diffusion of a large number of stoves at a lower cost than in rural areas due to availability of transportation and communication facilities, and higher purchasing power. The earlier survey of stove programs supports this statement.

The second situation is dissemination of stoves in areas where charcoal is the main fuel. As discussed in the previous chapter, consumption of firewood does not place significant pressure on forest resources because it consists of collecting fallen branches. In contrast, charcoal production is based on felling live trees. There are certain regions, mostly in arid areas, however, where the validity of this distinction may be questionable.

Both the above cases indicate strong potential for improved stoves in containing deforestation in Sub-Saharan Africa. However, the site-specific impact of stove programs on deforestation depends on the source of wood or charcoal supply to a particular locale. If fuel wood is obtained from logging or agricultural operations, improved stoves will not produce a significant result on forest depletion.

It is not easy to precisely ascertain the source of charcoal to every urban area, but there are scattered indicators. For instance, it is estimated that about 25% of charcoal supplies to Kinshasa comes from a logging site at the nearby town of Kasangula (Hill et al 1986, 25). This percentage has to be excluded when assessing the impact of improved stoves on deforestation in that area.

As discussed in Chapter 3, a good deal of wood supplies to Khartoum comes from the Blue Nile Province, over 500 miles away. Some of that land is cleared for mechanized farming, but in the early 1980s it was reported that about 239,200 hectares were cleared annually for charcoal supplies to the city. Taking the annual deforestation rate reported by FAO for the Sudan (500,000 hectares), charcoal consumption in Khartoum accounts for 48% of total forest depletion in the country. This represents a case where tangible results may be produced by improved stoves.

Hyman (1986, 158) estimates that if improved stoves were adopted by 80% of Kenya's charcoal using households in 1985, that would save about 967,000 tons of wood annually - assuming traditional charcoal conversion methods. On the other hand, some authors contend that improved stoves - of the type prevailing in the Sahel - would not effectively slow deforestation because of their limited scale. According to Massé (1985, 27), annual wood savings of a typical program represent about 0.03% of national fuel wood consumption.[43]

The environmental hazard of promoting improved charcoal stoves is that consumers may switch from firewood, and other fuels, to charcoal on a large scale. This will increase wood consumption because of the losses in charcoal

[43] He assumed that 900 stoves that saved 20% fuel were constructed, with 70% of them in regular use. The average urban family of 12 persons consumed 9.6 m^3 of fuel wood annually. Using the concept of half life, Masse inferred that the number of stoves under that program will never exceed 2,700. His assumptions are rather stringent since most programs in that area have achieved wider scale of dissemination. See the survey of stove programs in Africa at the beginning of this chapter.

production (Hyman 1986). This certainly is not a desired result in terms of wood cut, but other benefits of using charcoal may overwhelm the greater use of wood. It is reported that the Kenyan Jiko stove drew users from other fuels. Of the people who adopted the new stove 41% were former kerosene users, 49% used LPG, and 57% previously used electricity, though this was not a total switch from these other fuels (Jones et al 1989, 42).[44]

Emissions from biomass burning such as carbon monoxide, suspended particulates, hydrocarbons, and nitrous oxides are expected to decline as a result of the introduction of improved stoves.[45] Since some of these are known greenhouse gases, improved stoves have a potential in generating an impact on global warming via this route. However, the magnitude of this potential needs to be investigated. As explained in Chapter 4, greenhouse emissions from the household sector have not been addressed. Emissions from this source may turn out to be small, but if they do not, improved stoves provide a proven cost-effective way of reducing them.

Reduction of the above emissions has clear health benefits because they are known to cause serious respiratory and visual disorders. The KCJ reportedly

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[44] The percentages reflect the multiple use of fuels.

[45] Some of the modifications in stove design may merely alter the combination of emissions rather than reduce total emissions' levels (Smith 1985).

reduced emissions of carbon dioxide and carbon monoxide by 20%, as well as soot emissions (Namuye 1989, 42, Jones et al 1989). The Lorena stove was effective in reducing smoke. But this is misleading in the case of charcoal-burning stoves because charcoal emits toxins without smoke. One of the advantages associated with ceramic stoves is that they reduce the risk of burns when handled. This is an unambiguous improvement over metal stoves. The frequent incidence of fires is another global pollution link that merits investigation.

The environmental and health improvements cited above are unambiguous. However, when examined within the context of general public health needs in poor countries, these may not be of high priority. Optimization in the use of resources requires that detailed cost-benefit evaluation of the private and social costs of indoor air pollution and fires from traditional cooking methods be established. This is an area where more research is needed.

Naturally, it would be desirable if these benefits were realized as side-effects of using improved stoves, but their quanitification is important for determining the overall cost-effectiveness of improved stove programs.[46] As for the potential role of improved stoves in producing any

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[46] The levels of indoor air pollution from traditional methods of cooking are such that "cost-effectiveness and cost-benefit analysis indicate that it may be possible to justify improved stoves solely on the basis of the improved health resulting from lower smoke exposures." (Smith 1985, 285).

results on global warming, this cannot be determined until further research is undertaken to examine the nature and magnitude of greenhouse gas emissions from the household sector, and whether they are entirely offset by new vegetation growth.

3. The Economic Parameters Determining the Effect of Improved Stoves

The final factor that determines the success or failure of improved stove programs in containing deforestation is the economic parameters underlying the process itself, especially fuel wood consumption. The parameters of highest concern here are the elasticities of demand for fuel wood by households. The following section discusses the household's choice of fuel and the level of fuel wood consumption, as well as inter-fuel substitution.

3.1. Household Fuel Consumption Patterns

In less developed countries, households use a combination of modern and traditional fuels. This group of fuels includes electricity, LPG, kerosene, charcoal, and firewood. Charcoal is by far the most commonly used fuel in urban Africa, either on its own, or in combination with other fuels. The ratio of charcoal to firewood users in Kinshasa is 85:15 (Hill et al 1986, 6). For Khartoum the ratio is estimated at 95:5 (Jones et al 1989, 95). Firewood is used at lower income levels. It is highly unlikely to be found together with electricity or LPG in the same household.[47]

The reasons for using a combination of fuels are several. In poor countries, modern fuels are not always available. Supply constraints due to foreign exchange crunches have already been mentioned. Electricity supplies are not perfectly reliable even when it is hydro-generated. In Sub-Saharan Africa, electricity generation in the dry season is weak, hence outages that last several hours, sometimes days, are frequent. Risk minimization dictates that traditional fuels be kept stand-by. As noted earlier, social reasons for using traditional fuels may be just as strong.[48] Thus, the nature of the relation between fuels is more complementary than otherwise.

The literature on traditional fuels has indicated that consumption of fuels - both traditional and modern - is more strongly influenced by changes in income than by price fluctuations. As incomes rise, consumers move up from firewood to charcoal and kerosene, to LPG, then electricity. Users switch relatively easily from firewood to charcoal. However, the threshold for moving from charcoal to modern fuels is high. LPG tends to be of an

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47 Evidence to the contrary was observed in Nairobi. Firewood consumption exhibited erratic behavior in relation to income (Hughes-Cromwick 1985). See Chapter 3.

48 For Instance, some foods require certain cooking styles; charcoal is preferred to other fuels for the flavor it generates, while kerosene is not desirable because it transmits a "smokey" flavor to foods.

intermediary nature. Charcoal use persists because of the insecurity of LPG supplies. With further increases in income, consumers move to electricity but continue to use traditional fuels for the same reason. This pattern has been observed in Nairobi (Hughes-Cromwick 1985).

The big difference in price between traditional and modern fuels, and the cost of appliances for the latter, limit substitution possibilities. Prices of traditional and modern fuels do not lie far apart on the basis of cost per unit of energy content to users, as indicated in Table 5.1. Although these calculations do not indicate whether non-monetary costs associated with firewood are included. The table indicates that the costs to the user per unit of energy of different fuels, excluding appliance cost, are within a narrow range.[49]

For example, the price of charcoal and LPG in Ethiopia is $0.005 and 0.003 per mega joule (Mj) respectively. Thus, for the amount of work they deliver, modern fuels are even cheaper than traditional fuels. Even though the price of traditional fuels per volume is lower than that of modern fuels, this benefit is swamped by the lower efficiency of the former. This kind of evidence is frequently used to support proposals for substitution of traditional fuels by

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[49] These figures have to be taken extremely cautiously since a wide number of assumptions underlie them. For instance, sources do not always state the efficiency of different appliances, and the type of utensils used. Anderson and Fishwick (1984, 30) assume thermal efficiencies of 13% and 22% respectively for cooking with firewood and charcoal using metal pots.

modern ones in urban areas.

TABLE 5.1

RELATIVE COSTS OF HOUSEHOLD FUELS IN URBAN AREAS OF SELECTED COUNTRIES IN SUB-SAHARAN AFRICA, 1984-86
$/Mj

	Firewood	Charcoal	Electricity	LPG
Senegal[1]	0.003	0.003	0.022	0.008
Cameroon[1]	0.003	0.003	-	0.380
Ethiopia[1]	0.003	0.005	0.005	0.003
Zaire[2]	0.014	0.050	0.003	
Kenya[3]	4.301	4.930	89.070	76.78

Source: 1- Anderson and Fishwick, 1984; 2- Hill et al, 1986; 3- Hyman, 1986. This includes appliances costs.

When the cost of the initial capital outlays to acquire appliances associated with each fuel is included, the differences between fuels change considerably in favor of traditional fuels. This means that the choice of fuel is not only determined by the market price, but by other costs associated with use of each fuel as well. Table 5.1 shows that charcoal is relatively attractive from a private cost perspective. From a social perspective, charcoal is not so attractive due to its role in deforestation, especially given the low conversion rate from wood, using current methods. But consumers are not likely to abandon cooking with charcoal merely to save forests that appear to have no immediate bearing on their lives.

One of the problems with the type of analysis cited in Table 5.1 is that it compares the combination of household fuels on the basis of aggregate end use. For instance, Munslow et al (1988) maintain that electricity is superior to LPG. For general purposes this may be true, but electricity for cooking is an entirely different commodity from electricity for lighting or refrigeration. The latter represents the bulk of household demand for electricity in poor countries. In addition, even though LPG supplies are erratic, LPG can be stored; electricity cannot. That may explain why more people rely on the former.

What this review of fuel use patterns in households shows is that income is the predominant factor in determining the use of fuel. There seems to be an established pattern of ascendancy from traditional to modern fuels. Substitution between the two groups of fuels is determined, not only by the price, but also by other costs associated with the use of a particular fuel, mainly the cost of appliances. Therefore, to obtain cross price elasticity between the two, a composite price of modern fuels factoring all costs will likely yield more accurate results.

3.2. Improved Stoves and the Market for Fuel Wood

As the introduction to this work has indicated, the impact of improved stoves on deforestation is measured by permanent reduction in households' fuel wood consumption. This means that the external effects of stoves, i.e., the changes in fuel wood consumption that improved stoves inadvertently produce, need to be addressed. The underlying framework of the fuel wood market was introduced in Chapter 4. Here, improved stoves are imposed in order to examine how they might change that framework. Figure 5.4 is identical to Figure 4.1, except for the inclusion of improved stoves, which represent an exogenous shock to the system. The two agents directly affected by this shock are households, in the roles of consumers or producers.

The effect of improved stoves on fuel wood consumption has two components. The first is the first order reduction in fuel consumption. This reduction, mutatis mutandis, goes directly to wood resources as indicated by the arrows. The second component is price and quantity adjustments in the fuel wood market induced by first order effects. The second order effects are reflected on fuel wood prices which in turn send signals to consumers and producers for the appropriate quantity adjustment.

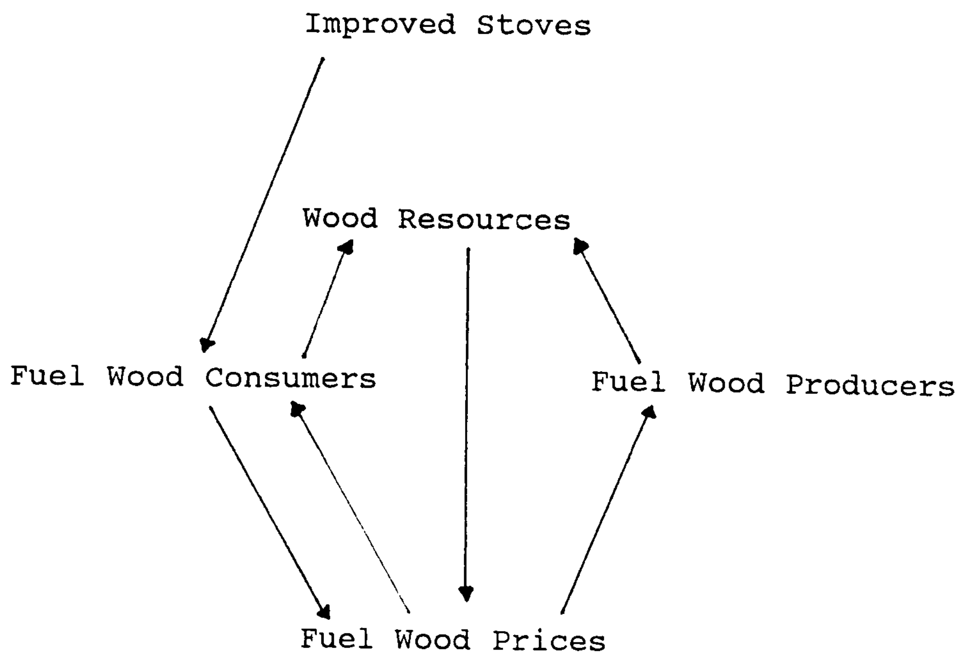

Fig. 5.1 Fuel Wood Market Adjustments in Response to Improved Stoves

It has already been stated that the standard approach for measuring the change in fuel wood consumption caused by improved stoves is based on multiplication of the engineering efficiency times the number of stoves in use. Hence, the fuel saving capacity of a stove is multiplied by the number of stoves disseminated to arrive at the total amount of wood saved. This is then transformed into the equivalent number of trees or forest area that would be spared, in order to establish the effect on deforestation. In the case of charcoal stoves, the amount of wood saved is multiplied by some factor of wood conversion to charcoal.

There are two problems with this approach. First, it focuses exclusively on the first order effects of stoves, i.e., the fuel savings determined by technological improvement in stove design. However, by definition, improved stoves are designed to generate changes or modifications in household behavior in relation to cooking, energy use, and so forth. These behavioral adjustments, which determine the second order effects, must be incorporated in the analysis of the impact of stoves on fuel wood consumption. The above approach falls short of that.

Second, the extent of deforestation is not linearly related to the amount of wood consumed, or even that produced, irrespective of the size of the conversion factor assumed. As discussed in Chapter 4, the severity of damage to forests is determined by the pattern of wood harvest, pressure on any certain piece of land, and the time allowed for recovery between harvests. As a result, the quantity of wood consumed is not sufficient to infer the effect of stoves on deforestation. There must be some qualitative evidence on the pattern of wood removal. This has been discussed in Chapter 4. The remainder of this section deals with households' response to improved stoves, and stoves' implications for fuel wood markets.

Lower fuel requirements due to efficiency improvement will generate savings to the household in the form of real income or labor time savings. The reallocation of these savings determines how improved stoves will affect fuel wood consumption. This is the conventional income effect. As argued in Chapter 4, the reduction in fuel wood demand will necessarily be followed by downward price adjustments. That may, in turn, give rise to further purchases. This is the familiar price, or substitution effect. <u>The income and price effects are the basic market adjustment responses to improved stoves.</u>

The secondary purchases of fuel wood can be thought of as leakages in fuel savings that reduce the effectiveness of stove programs. The magnitude of these purchases is determined by income and price elasticities of demand for fuel wood. In cases where these are sufficiently large, the policy of improved stoves may be self-defeating; in all likelihood, they will likely be smaller than the first order effect.

3.2.1 Income Effects

This section explains the mechanism by which the income effect gives rise to secondary purchases of fuel wood. Once a household starts using an improved stove, its fuel requirements are reduced by whatever amount made possible by the stove's fuel efficiency improvement. This is an exogenous technological shift factor. The review of improved stove programs at the beginning of this chapter indicated that efficiency improvement varies from 5% to as high as 60%. This first order result of stoves, here called the exogenous reduction in fuel consumption, causes a downward shift in the household's fuel wood demand schedule as Figure 5.2 illustrates.

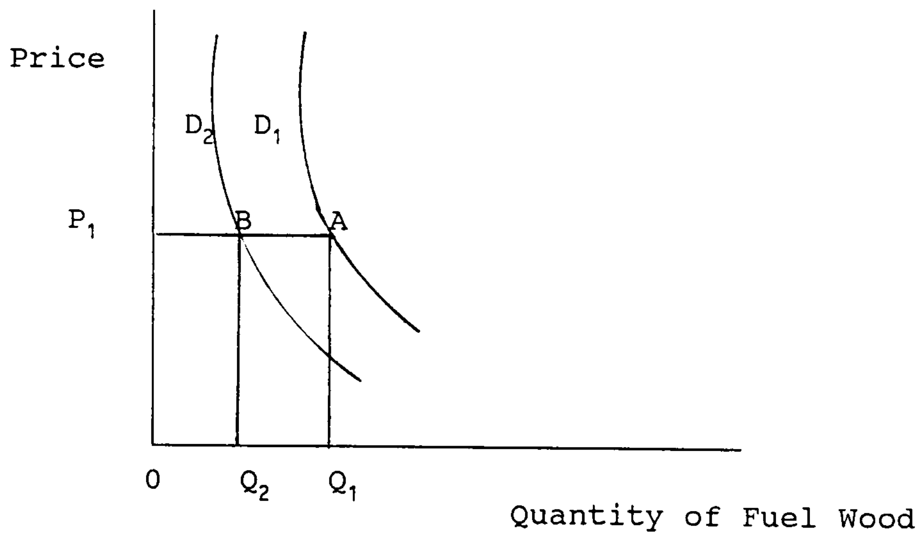

Fig. 5.2 First Order Effects of Improved Stoves
The Exogenous Reduction in Fuel Wood Consumption

Point A is the initial equilibrium position. P_1 and Q_1 are the pre-improved stove fuel wood price and quantity demanded by households. The exogenous reduction in consumption induced by technological improvement shifts the demand schedule from D_1 to D_2, indicating a new consumption level at Q_2. Q_1 Q_2 is the exogenous reduction in fuel wood consumption. This amount has been the subject of most previous studies of fuel savings. The rectangle ABQ_2Q_1 is the first order reduction in expenditures on fuel wood. It is equivalent to an increase in real income. This result is prior to any price adjustment.

The real income increase associated with using improved stoves may be substantial. In Kenya, the monetary savings from the Jiko stove were estimated at $18.8 annually. This is equivalent to half the average monthly wage in Nairobi (Jones et al 1989, 29). This real income increase is in itself one of the most important objectives of improved stoves for raising standards of living. Expectedly, the higher the efficiency improvement, and the higher the cost of fuel wood, the bigger will be the savings.

Increases in real income may also take the form of savings in time spent on either fuel wood gathering or in cooking. Reallocation of the freed time will determine how the overall consumption of fuel wood is affected. FAO (1991, 48) estimated that on average most improved stoves' users save an hour per day, at least half of which is rechannelled into income raising activities. In Senegal, family savings in the time required for fuel wood gathering and for cooking are estimated at 566 hours a year (Gueye and Madon 1983, 640). The KCJ stove was reported to save over 90% of the time taken for cooking by the traditional metal stove (Jones et al 1989, 39).[50]

The increase in real income has the effect of shifting the family's compensated fuel wood demand curve outward, because the household will use some of the extra income to increase expenditure on fuel wood. The compensated demand curve is, of course, relevant here since money income has not changed. In terms of preference mapping this elevates fuel wood consumers to a higher utility level by pushing the budget constraint upwards.

The amount of secondary fuel wood purchases induced by the income effect is determined by income elasticity of demand for fuel wood. A relatively large elasticity implies that improved stoves will induce a substantial increase in fuel wood consumption, thereby partially undermining the effectiveness of a stove program. A high budget share will yield a similar result. Figure 5.3 illustrates the income effect of improved stoves.

D_{c2} is the after-improved stove compensated demand schedule. It reflects the new fuel wood consumption after using the more efficient stove. The income effect generates a rightward shift in demand, say to D_{c2}. Q_4Q_3 is the increase in fuel wood consumption resulting from the income effect. If income elasticity is positive, i.e., fuel wood is a normal good, then the higher it is, the larger will be the

[50] Other authors reported that the KCJ did not alter the time used for cooking at all, and sometimes the traditional metal stove was even faster (Namuye 1989).

secondary purchases, and the bigger will be the leakages in the stove's effectiveness. If fuel wood is an inferior good, increases in real income may be largely reallocated to goods other than fuel wood.

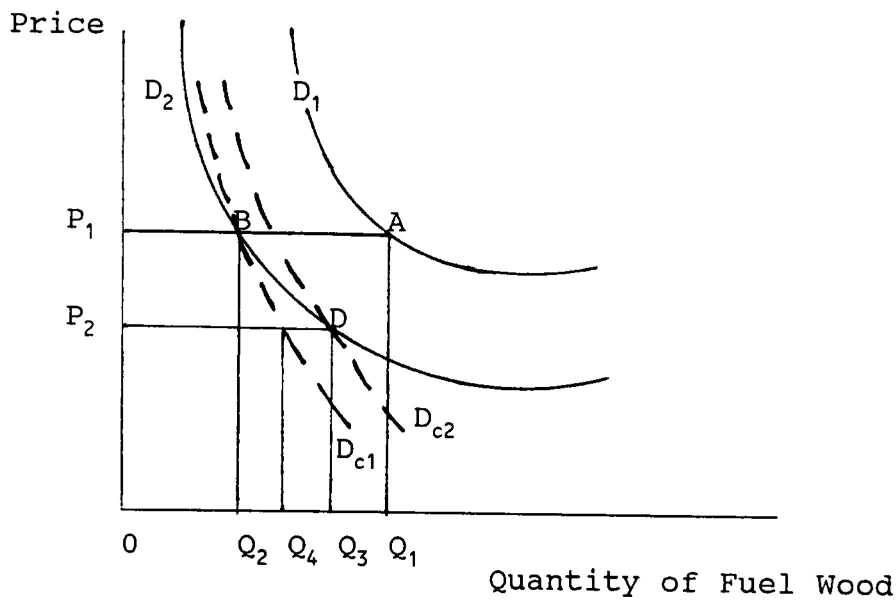

Fig. 5.3 Second Order Effects of Improved Stoves Income and Price Effects

Evidence indicates that at upper income levels wood is an inferior fuel.[51] In Nairobi, the relationship between income and fuel wood consumption reflects a two-tier pattern. Income elasticity is positive for low income groups, ranging from 0.18 to 0.69. For high income groups it is -0.67 (Jones et al 1989, 37). As a general rule, fuel

51 The literature survey in Chapter 2 showed that fuel wood was an inferior good, particularly in urban areas.

wood income elasticities in less developed countries have been consistently below unity. Results from the present study are not expected to deviate from that range. The implication of this observation is that income effects will not likely give rise to substantial secondary purchases of fuel wood.

3.2.2 Price Effects

The exogenous reduction in fuel requirements shown in Figure 5.2 will be followed, with various lags, by downward adjustments in fuel wood prices; since at the original price level P_1, the supply of fuel wood exceeds demand. Figure 5.3 illustrates the price adjustment process triggered by improved stoves. The first event, i.e., the exogenous fuel reduction causing quantities demanded to shrink from Q_1 to Q_2, is basically the same as explained in the context of Figure 5.2.

The process described in this graph reflects flexible prices. If price fully adjusts, this will bring about a new market clearing position at point D, where the quantity demanded increases in response to the drop in price. In reality, that may not take place. Price may not fully adjust to changes in fuel wood demand. If price falls to some point between P_1 and P_3, for instance, then the surplus will persist.

This downward price movement will, *ceteris paribus*, induce secondary fuel purchases by households, as well as consumers in other sectors. This is the price or substitution effect which reinforces the income effect. The secondary purchases induced by this effect are Q_2Q_4. The price effect, as is well established, is equivalent to a movement along the demand curve. Mere visual experimentation with the shape of the demand curve indicates that the higher the price elasticity, the larger will be the quantity adjustment accompanying improved stoves. If the household's demand for fuel wood is price elastic, then secondary purchases resulting from price adjustments will be more than proportionate to those adjustments.[52]

From previous discussions it became clear that the price effect is less certain than the income effect due to the lack of estimates of the parameters governing the relation of fuel wood prices to forest resources, especially in Sub-Saharan Africa. However, it is the hypotheses of the present study that fuel wood price elasticity is low due to the unavailability of close substitutes, as explained in the previous section.[53] At lower incomes most urban families have to be completely

52 In Chapter 3 it was explained that measuring the price effect requires finding the size of the price adjustment P_1P_2. This is determined by the combination of the exogenous reduction in consumption and fuel wood supply elasticity. Once the magnitude of the price adjustment is obtained, the household response is determined by price elasticity.

53 Substitutes to fuel wood are not confined to other fuels, but extend to all practices undertaken to reduce consumption such as those discussed in Chapter 4. These are still limited, though.

impoverished before turning to inferior fuels, such as crop residues. On the other hand, modern fuels are highly priced, and the cost of appliances is another obstacle to substitution.

The price effect is mitigated by two factors. The first is an endogenous one stemming from the upward price movement accompanying the income effect. The exogenous factor has to do with the process of forest depletion itself. Earlier it was suggested that in the short run, or in the absence of replanting, the process of deforestation may be represented by price hikes in successive time periods. Admitting market adjustments - but bearing in mind that quantities are not highly flexible - prices must rise considerably in response to increasing costs of obtaining fuel wood. In effect, progressive deforestation may postpone the downward movement in prices, resulting in a small price effect.[54]

This is so because the only element of forest depletion that has any bearing on fuel wood prices is the variable cost embodied mainly in transportation and production factors not related to the stock of the forest itself. The cost of replacement of the forest is not relevant unless the forest is grown on a sustainable yield basis, or is at least managed in some form. Since

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[54] Other exogenous dynamic factors such as population growth and rapid urbanization may have the same effect.

transportation cost is directly related to the extent of forest disappearance, it indicates the progress of deforestation.

Thus, on the whole, the introduction of improved stoves, places an upward pressure on quantities of fuel wood consumed.[55] The same mechanism will take place in other sectors in the economy. Traditional industries may use improved stoves. This technological improvement will reduce their average costs, thereby inducing larger output levels. To the extent that this is a productive activity, improved stoves could be promoted in industry.

Summary and Conclusions

1) This Chapter has surveyed improved stove programs in general, and in Sub-Saharan Africa in particular, with special emphasis on The Sudan. The survey showed that there is a large number of programs, but few are successful. Three main factors determine the overall impact of improved stoves on the rate of deforestation. These are: the ability of stoves to improve the efficiency with which fuel wood is burnt; the extent of dissemination of stoves; and the

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[55] The relative size of the income and price effects may partly depend on the speed or the timing of each. In other words, it may depend on whether the household response to lower fuel requirements precedes or follows adjustments in fuel wood prices. Price adjustment is likely to be relatively slow given rigidities in the fuel wood market. On the other hand, if households' behavior is largely determined by habit, then the income effect may follow price adjustments. The reason why this may affect the relative size of the income and price effects is that the former impacts the compensated demand schedule, while price adjustment operates on the Marshallian demand function. If all the relevant demand curves were parallel, path dependency would not be an issue. In any event, this point is rather trivial since the final result with respect to the total change in fuel wood consumption and prices is not affected.

parameters governing fuel wood markets, which will determine the response to stoves by households, as well as by other sectors.

2) Improved stoves have been shown to save fuel; some have achieved remarkable savings. However, evidence needs to be strengthened. The ability to diffuse stoves on a large scale has been a challenge few programs were able to overcome with a reasonable degree of success, e.g, Kenya and China. With respect to the third factor, it is argued that the characteristic parameters of fuel wood markets, i.e., relative smallness of demand and supply elasticities, are likely to reduce the overall secondary effects generated by improved stoves on fuel wood demand. Thus their effectiveness in slowing deforestation is not expected to be greatly reduced.

The next Chapter estimates fuel wood demand and supply parameters in Khartoum in order to test the last prerequisite for improved stoves to reduce fuel wood consumption substantially, i.e., that fuel wood elasticities are small. Results are used to examine the effect of improved stoves there on fuel wood consumption in the city, and how that will affect deforestation in the area. The applicability of results to Sub-Saharan Africa is also investigated.

CHAPTER 6

RESULTS OF ESTIMATION, AND EVALUATION OF IMPROVED STOVES

Chapter 3 explained the model used for evaluation of improved stoves in Khartoum, and the auxiliary equations used to substantiate the results. This chapter states the results of estimation and analyzes them in comparison with results derived by previous authors. The chapter falls in three sections. The first reports the results of econometric estimation. In section 2 results are used to estimate the impact of improved stoves introduced in Khartoum on the demand for charcoal. The final section discusses the overall results and reviews their implications to the issues raised in this study, particularly deforestation.

1. Econometric Results

The results of estimation show that demand for charcoal in Khartoum exhibits the standard characteristics of a demand function. The same goes for demand in the cross-section of African countries. Both income and price elasticities are below unity. Supply of charcoal in

Khartoum is inelastic as well. These results are consistent with the hypothesis that the fuel wood market is characterized by low elasticities. The details of these results are reported in the following section. Results of the model estimation are summarized in Tables 6.1 and 6.2.[1]

1.1 Household Demand for Charcoal in Khartoum

The estimated charcoal demand equation is:[2]

$$\text{Ln } Q_{dt} = \underset{(0.70)}{2.77} - \underset{(0.18)}{1.12} \text{ Ln } P_t + \underset{(0.13)}{1.28} \text{ Ln } Y_t + e \qquad (6.1)$$

The model has a good fit indicated by the (F) test, which has a value of 111.82, and is significant at all levels.[3] Adjusted R^2 indicates that the model equation explains 88% of the variation in the data. All coefficients are significant at all levels.

As Table 6.1 reflects, the estimated model shows the expected signs. Thus, household demand for charcoal varies inversely with price, and directly with income. Initial estimation shows elasticity values of 1.12 in the case of price to 1.28 for income. No serious case of

[1] For detailed results see the Appendix A-1 and A-2.

[2] Figures in parentheses are standard errors.

[3] The (F) statistic indicates the overall significance of the model, or the combined effect of all the independent variables, such that all the coefficients are different from zero.

multicollinearity has been detected. The Durbin-Watson statistic (D.W.) indicates the presence of a somewhat significant problem of first order serial correlation. Hence, the equation was estimated again using the Yule-Walker (Y-W) procedure for correction. Results were as follows:

$$\text{Ln } Q_{dt} = \underset{(0.79)}{4.9} - \underset{(0.20)}{0.55} \text{ Ln } P_t + \underset{(0.14)}{0.87} \text{ Ln } Y_t + e \qquad (6.2)$$

TABLE 6.1

ESTIMATION RESULTS
HOUSEHOLD DEMAND FOR CHARCOAL IN KHARTOUM

Estimation Technique	Parameters			R^2	F	D.W.
	a	α	δ			
OLS	2.77	-1.12	1.28	0.88	111.8	0.69
P Value	0.0005	0.0001	0.0001			
S Error	0.70	0.18	0.13			
OLS Y-W	4.90	-0.55	0.87	0.95		
P Value	0.0001	0.0096	0.0001			
S Error	0.79	0.20	0.14			

NOTE: (a) is the coefficient for the constant term. α is the own price elasticity, and δ is income elasticity of demand. The P value is the probability that the true parameter is different from the one estimated here. Thus, a low P value indicates high significance. S error is the standard error.

The explanatory power of the model increased significantly. Adjusted R^2 rose to 0.95. The income coefficient is still significant at all levels, but its standard error has risen. Significance of the constant term has improved together with relative standard error. The price coefficient is now significant only at the 1% level, i.e., there is 99% confidence that price elasticity is different from zero. This is an acceptable confidence level. However, the standard error now represents 36% of the parameter estimate compared to a previous 16%.

Elasticity estimates for both income and price declined considerably. The price and income elasticities are now 0.55 and 0.87 respectively. This indicates that a 1% increase in the price of charcoal results in a 0.55% drop in household consumption, whereas the same increase in household income yields a 0.87% increase in consumption. On the whole, households' demand for charcoal is relatively inelastic with respect to both price and income. The present estimate is larger than previous results of income elasticity of demand for charcoal in Khartoum arrived at by the Department of Statistics. In 1968, income elasticity was 0.66. By 1980, it had turned to -0.59, indicating that charcoal had become an inferior good.

To summarize, the results of estimation of demand for charcoal by households in Khartoum show that charcoal is a normal good that responds negatively to prices. Demand is inelastic with respect to both income and price, with elasticities falling below unity.

1.2 Supply of Charcoal in Khartoum

Results of estimation of the supply function are generally good. The estimated equation is:

$$\mathbf{Ln\ Q_{st} = 12.09 + 0.26\ Ln\ P_t + e \qquad (6.3)}$$
$$\mathbf{(0.02)\ (0.03)}$$

The model has a good fit. The (F) statistic stands at 74.25, and is significant at all levels. Adjusted R^2 indicates that 90% of the variation in the data can be explained by the estimated equation.

Results in Table 6.2 show that the price coefficient is significant at all levels and has the expected positive sign.[4] Thus, quantities of charcoal supplied vary directly with prices. There is no serious problem of serial correlation, hence the results of the OLS estimation are maintained. The supply elasticity of charcoal is 0.26, indicating that a 1% increase in price induces an increase in quantities supplied by 0.26%. Therefore, supply of charcoal is also relatively inelastic. This confirms the

[4] Identification of the supply and demand functions is not a major problem here, due to the fact that even though both functions are shifting over time, they have different shift factors. Transportation cost is the main parameter differentiating supply from demand. As noted already in Chapter 3 [section 2.2], the supply function has been estimated with transportation cost as an explanatory variable. The price coefficient still retained its positive sign, indicating that this is in fact a supply rather than a demand relation.

hypothesis of the previous chapters.

TABLE 6.2

ESTIMATION RESULTS
CHARCOAL SUPPLY IN KHARTOUM

Estimation Technique	Parameters		R^2	F	D.W.
	d	ϕ			
OLS	12.09	0.26	0.90	74.25	1.43
P Value	0.0001	0.0001			
S Error	0.02	0.03			
OLS Y-W	12.10	0.25	0.92		
P Value	0.0001	0.0005			
S Error	0.03	0.04			

Note: d is the coefficient for the constant term.
ϕ is supply elasticity.

1.3 Household Demand for Charcoal in The Sudan

The above results apply only to one city: namely Khartoum. It is important to examine the situation at a broader scope. For that purpose demand for charcoal was estimated for The Sudan. Results are summarized in the Appendices A-3 and A-10. The estimated equation is:

$$\mathbf{Ln\ Q_{dt} = 8.21 - 0.53\ Ln\ P_t + 0.71\ Ln\ Y_t + e} \qquad \mathbf{(6.4)}$$
$$\mathbf{(0.86)\quad (0.15)\qquad (0.12)}$$

The initial results were not impressive. The model has a reasonably good fit. Adjusted R^2 is equal to 0.79. Thus the model explains approximately 80% of the factors determining charcoal demand by households in the country. The (F) statistic is a modest 58.22, but it is significant at the 0.0001 level. The constant and the income terms are also significant at all levels, with relatively low standard errors. The equation shows the same signs as the previous one. Charcoal is a normal good. Even though the price coefficient has a negative sign, price is significant only at 0.0016.

Collinearity is high, which indicates that parameter estimates may not be accurate. There is also a rather serious case of first order serial correlation. After correction for that problem the overall fit of the model improved. R^2 rose to 0.93. However, the price coefficient became totally insignificant. Its standard error stands at 92% of the parameter estimate. In other words, the estimate is totally unreliable.

When the price variable in the equation was lagged for a one year period, the results improved dramatically.[5] The overall fit improved by 31%. R^2 rose to 0.84. Significance improved for all variables. The price coefficient is now significant at all levels. All standard errors declined.

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[5] It is quite possible that a shorter lag, e.g., one quarter, may produce better results. Present data does not allow that.

Collinearity declined but still poses a problem. After correction for serial correlation R^2 rose again to 0.93. The price coefficient is significant at the 5% level, with a relatively sizable standard error. Thus, the estimated equation for household charcoal demand in The Sudan, after correction for serial correlation is:

$$\mathbf{Ln\ Q_{dt} = \underset{(0.70)}{10.06} - \underset{(0.13)}{0.25}\ Ln\ P_{t-1} + \underset{(0.10)}{0.44}\ Ln\ Y_t + e} \qquad \mathbf{(6.6)}$$

These results are not thoroughly impressive, but they can be used to establish the direction of the price-quantity relation. All estimates should be taken with care due to the presence of significant multicollinearity. The quantity of charcoal demanded varies inversely with price, though it is not possible to make definitive statements about the size of that variation. The price elasticity estimate of 0.25 should be taken cautiously. This estimate is less than half the one for Khartoum. The results also indicate that at the national level consumption responds to prices with a lag, i.e., more slowly than in the capital city. The low estimate may be attributed to greater availability of substitutes in urban areas.

The estimate for income elasticity is 0.44, that is also much lower than for Khartoum. This is unexpected. From the review of previous studies in Chapter 2, it was clear that income elasticity for traditional fuels was higher in rural areas in all cases, except when they were inferior goods. Then, the elasticity was higher in urban areas, reflecting an underlying tendency to substitute into modern fuels as incomes increased.

In urban areas the whole continuum of substitutes for charcoal can be found. This ranges from electricity and LPG, to kerosene, to firewood on the peripheries of the city. Even crop residues are available from a few agricultural projects around Khartoum. In rural areas electricity and LPG are not available. Substitutes are confined to wood, crops, and dung in remote areas, and rarely kerosene. In desert areas crop residues are not a viable option. This is the case in the Northern Region of The Sudan. As a result, price elasticity for the country is expected to be lower than that for the capital city.

This explanation is supported by the finding that at the national level consumption responds to price changes only after a lag. Thus, it takes consumers longer to adjust their consumption levels in rural areas. This in part may be due to stronger habit formation factors, where households are more bound by tradition and habit than in urban areas. In addition, as part of the monetary economy, market structures are relatively more developed in urban centers.

The income elasticity estimated here may be biased in either direction depending on the pattern of income distribution in the sample used here. The reason is that with charcoal being an intermediate fuel, the demand side of the charcoal market is segmented. Charcoal consumers fall into three main categories: a) hard core charcoal users who rely on it all the time, b) households that principally use LPG or electricity but resort to charcoal during times of scarcity as explained in Chapter 5, and these are mainly urban dwellers, and c) consumers who use firewood predominantly but are able to afford charcoal periodically.[6]

The coefficient for income elasticity reflects all three segments because the income proxy used here (GDP) is highly aggregated. Hence, δ will be biased downwards if group (b) forms a large percentage of total income, whereas if group (c) is dominant, income elasticity will suffer from an upward bias. The more skewed income distribution is, the more downwardly biased is income elasticity. If charcoal is an inferior good at the upper income levels - as has been demonstrated in several countries in Sub-Saharan Africa -, the downward bias will be even greater.[7] In the case of Khartoum this bias can be expected to be higher than for the entire country due to the fact that

[6] Charcoal, and sometimes firewood, is occasionally used by this group for social gatherings and for preparation of traditional dishes that require certain flavoring methods.

[7] For cases of negative income elasticity of demand for fuel wood see the review of the literature on demand for traditional fuels in Chapter 2.

most LPG and electricity users live in the capital city.[8]

On the other hand, at lower income levels, poorer consumers, mainly firewood users are likely to have a larger income elasticity than consumers at higher income strata. Thus, this group may contribute an upward bias to income elasticity. The net bias of income elasticity depends on the relative sizes of these groups, and the pattern of income distribution in Khartoum and in The Sudan in general. Information on income distribution is inadequate and unreliable, especially given continuous demographic changes caused by migration and rapid population growth. This has to remain an area for future research.

As for the bias caused by LPG consumers, it is not expected to be of any consequence. In 1989, LPG consumption as a percent of household consumption of energy for cooking was less than 1% (SNEA 1991). In this context, results from the equations estimated with LPG indicated that LPG is complementary to fuel wood rather than a substitute. This is reflected in the positive cross price elasticity between the two.[9] As mentioned in Chapter 2, this phenomenon has been observed in other places in Africa.

This discussion of income elasticities in relation to

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[8] It is worth mentioning that with regard to deforestation, group (b) has more adverse implications because members of this group are likely to use fuel wood more wastefully than the other two groups since they are less concerned with financial costs.

[9] See Appendix A-8, A-9.

income distribution is supported by Fernandez' findings for The Sudan. Her results indicated income elasticities of 0.51 for urban areas, 0.55 for semi-urban areas, and 0.80 for rural areas in 1967-8. This reflects that income elasticity tends to fall with successive rise in income groups, which clearly indicates the direction of the bias suggested above.

1.4 Demand for Charcoal in Sub-Saharan Africa

Results of the demand equation for the 20 African countries show that charcoal is a normal good, with an income elasticity of 0.85. After correction for serial correlation it rose to 0.86. That is remarkably close to the results for The Sudan. The income variable is significant at all levels. R^2 indicates that the model explains over 60% of the variation in the data. This equation follows the tradition of estimating Engel curves, instead of full demand equations, for biomass energy in Sub-Saharan Africa as a result of lack of price data.

Since the above equation does not include a price variable, a demand function was estimated for eight countries for which price data are available.[10] The model has a poor overall fit (the F statistic is 8.44).[11] The

[10] Results for this equation and the previous one are reported in Appendix A-5, A-6.

[11] Multicollinearity for this equation is low. This is a welcome result. Since colinearity signifies correlation among independent variables, this finding implies that the income elasticity estimate from the previous equation is not biased upward by the absence of the price variable.

results show a negative relation between price and quantity demanded. But the price coefficient is significant only at the 10% level. Accordingly, results from this equation are deemed not satisfactory enough to quote price elasticity.

The results show that the income coefficient is positive, i.e., charcoal is a normal good. However, this parameter is significant at the 1% level, which is not very good. The estimate for income elasticity is 1.31, which is higher than most estimates for traditional fuels in the region. In addition to data inadequacy, these modest results can be attributed to the small number of observations that makes it difficult to establish trends on a cross country level.

The demand equation estimated for Burkina Faso also produced somewhat modest results [Appendix A-7]. Results indicate that charcoal consumption is negatively related to price, but the coefficient is not significant. The negative sign persists even after correction for autocorrelation. Income elasticity is 0.78, significant at 0.0012. Again this is in the neighborhood of elasticities estimated for The Sudan and the region. The model explains about 94% of the variation in the data. This supports the existence of a demand relation. However, the small sample size precludes the ability to obtain statistically significant results with respect to demand variables.

The result that charcoal in other countries in Sub-Saharan Africa is a normal good signifies a reversal of trends found by previous studies of the region. Charcoal was found to be an inferior good in Nairobi and in Ghana. As noted earlier, results by the Sudan Department of Statistics showed that charcoal was an inferior good in the early 1980s. The present results may reflect the decline in real income in Sub-Saharan Africa since 1980, which also confirms the established relationship between poverty and higher reliance on traditional fuels.

2. Improved Stoves and the Demand for Charcoal

In Chapter 5 it was argued that the effect of improved stoves on fuel wood consumption is not likely to be undermined by second order effects because the fuel wood market is characterized by small quantity adjustments. The above results have confirmed the latter part of this statement. The remainder of this chapter is devoted to examining the implications of the present findings for improved stoves and for policy concerning deforestation in general.

The evaluation is based on two types of improved stoves that were introduced in The Sudan: the Ahfad and the CES stoves.[12] The Ahfad stove has modest fuel savings of 7%. As mentioned earlier, it is selected for the case study

[12] See Chapter 5, section 1.2.

because it is the only stove for which results of efficiency testing are available, and because it represents a lower bound for stove fuel efficiency. Fuel savings from the CES stove are claimed to reach 50%, so it serves as the upper bound case. The CES stove is currently widely disseminated in Khartoum as well as in a number of other towns. The results naturally apply to all stoves of the same fuel efficiency.[13]

2.1 The Income Effect

As noted in Chapter 3, the income effect is obtained by multiplication of fuel efficiency improvement, times the household budget share and income elasticity. Income effects are calculated for three cases. The baseline case (A) utilizes the parameters estimated in this study. Hence, this case is based on an income elasticity of 0.87. The budget share used here (10%), is based on estimates by The Sudan Department of Statistics as explained in Chapter 3. Results for the baseline case are summarized in Table 6.3 below.

[13] For a review of the methodology for obtaining the income and price effects the reader is referred to Chapter 3, section 2.2.

Table 6.3

THE INCOME EFFECT OF IMPROVED STOVES
BASELINE CASE

Income Elasticity	0.87
Household Budget Share	10%
Fuel Leakages	8.7% of Stove's Efficiency

Note: The budget share is based on estimates for Khartoum by The Sudan Department of Statistics, and by Jones et al, 1989.

The remaining cases offer simulations of the results on the basis of alternative parameters. As Table 6.4 indicates, case (B) is based on alternately doubling the income elasticity and the budget share while holding the other constant. Case (C) represents the extreme situation where the budget share is doubled and income elasticity is raised to unity.

TABLE 6.4

THE INCOME EFFECT OF IMPROVED STOVES
SIMULATION RESULTS

Case	Leakage in fuel savings
B- Income Elasticity 0.87 Budget Share 20%	17.4%
C- Income Elasticity 1.00 Budget Share 20%	20.0%

Doubling income elasticity is not as critical as doubling the budget share. Doubling income elasticity raises it to 1.74, which is unreasonably high given that so far the overwhelming majority of income elasticity estimates for traditional fuels in less developed countries has fallen below unity. Thus, unity is believed to be a plausible upper bound for income elasticity. The results of the second equation for Sub-Saharan Africa represent an outlier that merits further investigation. But given that these findings are not statistically significant, a unity upper bound for income elasticity is justified.

On the other hand, the share of fuel wood, particularly charcoal, in households' budgets has risen steadily due to the sharp increase in prices not matched by an equivalent increase in income. In some Sub-Saharan countries the budget share is estimated to have reached a quarter of income in urban areas.[14] Accordingly, raising the budget share to 20% is a plausible reflection of the current situation.

The baseline case, where the budget share is 10%, results in the most modest fuel leakages [Table 6.3]. If the Ahfad stove is adopted, then the household realizes an increase of 0.7% in real income. Since income elasticity is 0.87, consumption of fuel wood will increase again by approximately 0.61%. That represents a leakage of 8.7% from

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[14] See Chapter 4, section 2.5.

the stove's efficiency. The new stove still realizes 6.4% fuel savings. If the CES stove is considered, charcoal purchases by households rise by 4.35%. The stove still saves about 41.30% fuel.

Thus, based on the parameters estimated here, income-induced second order effects of improved stoves amount to 8.7% of fuel savings. This is compared to the 20% leakage arrived at by Jones. Jones used an income elasticity of unity and a budget share of 20% (1980, 256). If that budget share is adopted [Case B], the leakage rises to 17.4%. The income effect is still relatively small, but closer to his results. In case (C), where the income elasticity is unity and the budget share is 20%, the leakage in fuel savings rises to 20%. This is the same result as Jones'. It is considered an extreme case based on previous studies and the present findings concerning income elasticity.

To summarize, the income effect of improved stoves in Khartoum results in a leakage in stoves' fuel efficiency ranging from 8.7% to 20%, with 17.4% being a plausible middle ground. Applying the estimated income elasticity for Sub-Saharan Africa, and using a budget share of 20% gives income-related second order effects of 17%. For Burkina Faso, the corresponding figure is 15.6%.

2.2 The Price Effect

To remind the reader, the price effect is obtained by multiplying the price adjustment following the introduction of improved stoves, by the household price elasticity. The price adjustment is calculated as the multiple of the logarithm of supply elasticity and the exogenous reduction in fuel consumption. Applying the formula in equation 3.5 [Chapter 3], and based on the present finding that price and supply elasticities are -0.55 and 0.26 respectively, yields the following results.

The price adjustment following introduction of improved stoves is equivalent to a 4% drop in the price of charcoal in the case of the Ahfad stove, and 29% for the CES stove. This indicates that the higher the fuel savings achieved by stoves, the larger will be the consequent price movements. However, secondary purchases of charcoal, resulting from price adjustments are not proportionate due to low price elasticity. Price-induced secondary purchases of charcoal are on the order of 2.25% and 16.09% for the Ahfad and the CES stove respectively.[15] These purchases amount to a leakage in fuel savings from improved stoves of 32%.

Therefore, the price effect is considerably larger than the income effect. This confirms the hypothesis that fuel wood quantity adjustments are limited, hence placing most of the burden of market adjustment on prices. Previous findings on fuel wood price elasticities in less developed

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[15] For the formula for the price effect see Chapter 3, equation 3.5.

countries show that these are lower than the one estimated here (Jones 1988). This implies that on the basis of previous studies the price effect may be smaller than that obtained here.

2.3 The Overall Effect of Improved Stoves

On the basis of the parameters estimated in this study, and considering both the income and the price effects, households' purchases of charcoal in Khartoum will first decrease by the amount of the stove's fuel saving capacity, then increase by 2.9%, and 20.4% following the introduction of stoves with efficiency improvement of 7% and 50% respectively.

The first stove (Ahfad) saves about 4.15% of fuel wood used, while the CES stove reduces charcoal consumption by about 29.65%. Thus, in the baseline case, the two stoves realize about 60% of their designed efficiency improvement. Therefore, the loss in fuel efficiency from secondary purchases of fuel is slightly lower than estimates by previous authors. If the budget share is raised from 10% to 20%, efficiency leakages rise to almost 50%.[16] Table 6.5 shows the total effect of the two models of improved stoves considered here on consumption of fuel wood.

[16] The budget share involves a trade-off between the income and price effects in the following way. An exogenous increase in fuel wood prices will raise the budget share, thereby increasing the income effect. At the same time, the price increase offsets downward price adjustments, hence resulting in a smaller price effect.

TABLE 6.5

TOTAL REDUCTION IN HOUSEHOLD CHARCOAL CONSUMPTION RESULTING FROM IMPROVED STOVES INTRODUCED IN KHARTOUM

Case/Stove Type and Efficiency	Ahfad Stove, 7%	CES Stove, 50%
A-Income Elasticity 8.7 Budget Share 10%	4.15%	29.65%
B-Income Elasticity 8.7 Budget Share 20%	3.54%	25.3%
C-Income Elasticity 1.00 Budget Share 20%	3.35%	23.93%

Three cases of efficiency leakages are shown. In the unlikely case of doubling both the income elasticity (1.74) and the budget share (20%) - the case is not shown -, the effectiveness of improved stoves is reduced by almost 68%. However, as argued earlier on, doubling the income elasticity is unrealistic in light of the current literature on income elasticities of traditional fuels. These fuels have been demonstrated to be relatively income inelastic in almost all less developed countries.

These simulations indicate that the higher a stove's efficiency, the more effective it is in terms of the total effect on the demand for fuel wood. However, the higher the efficiency, the more sensitive fuel savings are to changes in parameters. An increase in the budget share produces a more pronounced effect on the CES stove than the Ahfad. The difference in secondary purchases of fuel wood resulting from doubling the budget share is 5.65% for the CES stove, compared to less than 1% for the Ahfad stove.

At the Sudan national level, improved stoves are likely to be more effective than in the capital city because demand elasticities are lower in the former. Assuming a 10% budget share, the leakage in efficiency is 4.4%. Hence, the income effect reduces fuel savings by less than 5%. Secondary purchases of charcoal will be between 0.31% and 2.2% of total demand. It is not possible to calculate the price effect for The Sudan due to the absence of an estimated supply equation. Clearly, differences between urban and rural areas will have to be taken into consideration.[17]

For other Sub-Saharan African countries the effectiveness of improved stoves is likely to be of the same order of magnitude as it is for The Sudan since demand parameters are very similar. Stoves may more effective in those countries where income elasticity is negative, i.e., Kenya and Ghana. In countries such as Mali and Niger, the potential may not be as high due to the larger share of fuel wood in household budgets.

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[17] Household' demand for charcoal was estimated for a cross section of provinces in The Sudan for 1990. The equation does not include an income variable due to lack of data. Results indicate that the model explains over 70% of data variation, though the F statistic is relatively low. The results show that price does bear a negative relation to households' consumption of charcoal across the country, with a 1% level of significance. The price elasticity coefficient is exceptionally high (4.03), which raises the possibility of unreliable data. Also, the sample is relatively small. Accordingly, this equation is used as no more than an indicator of the <u>direction</u> of the relation between charcoal consumption and prices. For results see Appendix A-4.

Long run elasticities are not estimated here, but the ramifications may be stated briefly. A tendency for income and price elasticities to rise in the long run will reduce the future effectiveness of improved stoves. On the other hand, since supply elasticity is always higher in the long run, these future prospects are enhanced because price effects will be weakened by the larger supply elasticity. Also in the long run, forest resources may be expanded by other measures undertaken to contain deforestation such that the implications of low elasticities for quantity adjustments may not be severe as in the short run.

The results indicate that secondary purchases of fuel wood induced by improved stoves are not large enough to totally undermine stove projects. But these results must be taken cautiously due to the possible lack of effective demand in the case of income elasticities, and immature market structure that weakens responses to price signals with respect to price elasticities. In the present study, these issues have been avoided by estimating demand for charcoal, as opposed to fuel wood as a whole, where charcoal is entirely commercialized.

When results are generalized to the fuel wood market by including firewood, price elasticity estimates derived may be biased downward since only a section of consumers respond to price signals. In that event, second order effects of stoves in actuality will be bigger than those estimated. On the other hand, in the literature, income elasticity for firewood is consistently negative. The case for charcoal is not so unambiguous. Hence, income elasticity for fuel wood in total may be lower than the present estimate. This, of course, enhances the impact of improved stoves on fuel wood consumption.

To summarize, the fuel wood market in The Sudan and in Sub-Saharan Africa is characterized by low demand and supply elasticities, which leads to low quantity adjustments. This is confirmed by the finding that the income effect of improved stoves on fuel wood consumption is relatively small. It is also confirmed by the large price effect. This means that introduction of improved stoves will be followed by relatively sizable movements in fuel wood prices.

3. Implications for Deforestation

The implications of this analysis for deforestation in The Sudan can be gleaned by looking at the extent of deforestation caused by charcoal consumption. From Chapter 3 it is estimated that about 239,200 hectares of savanna land are destroyed annually to supply Khartoum with charcoal. If improved stoves function as desired, with a 100% penetration ratio, and based on the parameters estimated here, then between 9,927 and 70,923 hectares may be annually saved considering the Ahfad and the CES stoves respectively [Table 6.5].

It can be seen that the stove designed to save 50% fuel can be rather effective. A saving of over 70,000 hectares per year is significant. Even assuming that stoves are used by only half the households, the savings are still worthwhile, ranging approximately between 5,000 and 35,000 hectares per year. A more likely scenario is where improved stoves save roughly 25% of the fuel wood used. This translates into 59,800 hectares annually if stoves are used by all households.[18]

The price effect may be considerably mitigated by the accelerated pace of deforestation itself. As argued in Chapter 5, the expected price adjustment may be smaller than calculated here or may not come about at all due to the presence of such dynamic factors as the progress of forest depletion and population growth. This element is not measured here due to the static nature of the model used in the present study, but it is important to consider when evaluating improved stove programs.

At the Sudan national level it is estimated that fuel wood consumption, mostly charcoal, is responsible for the destruction of about 31,000 km^2 (3.1 Mn hectares) annually. This reflects a threefold increase from 1960 (Whitney et al 1987, 319). If charcoal represents at least 60% of total

[18] These calculations are on a theoretical level, abstracting from details such as stoves' lifetime and part-time use of stoves by households. At any rate, the range is wide enough to encompass all these aspects.

fuel wood consumption, then about 1.86 Mn hectares are destroyed by charcoal consumption annually.[19] There is a potential for saving 77,004 to 551,490 hectares annually, and 465,000 hectares for the intermediate case.

Whitney et al (1985, 19) estimated that based on 1983 consumption, improved charcoal stoves would save about 300 km^2 annually. Mukhtar (1981, 75) estimated that the total amount of wood removed annually for the production of charcoal for the whole country is approximately 3 million tons.[20] Given that at the present time no reforestation efforts are seriously contributing to expanding the forest area, and that transportation will not be improved in order to supply deficient areas from wood surplus areas in the country, improved stoves represent an opportunity worth pursuing.

Future prospects for charcoal production add another dimension to this situation. Trends show that there is a movement from firewood to charcoal even in rural areas. About 90% of the average annual increase in deforestation can be explained by expanding use of charcoal. Per capita deforestation from the use of charcoal in rural areas increased by 161% from 1960 to 1980, while the population

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[19] Whitney et al (1985, 8) estimated that wood clear-cutting for charcoal production represented about 62% of annual losses in total wooded area in The Sudan. Partial destruction of trees for firewood contributed the remaining 28%.

[20] This type of estimate is not recommended because it equates deforestation with the amount of wood removed. See Chapter 4.

of these areas grew by 38% during the same period (Whitney et al 1987, 325).[21]

To stress again, these results can be generalized in terms of stove efficiency, not in terms of deforestation unless the source of fuel wood is determined to be tree cutting for that purpose. But even if that is not the case, the wood saved can be exported or used as wood products domestically, which contributes to a higher income level. This helps arrest deforestation, which is a poverty condition. In the final analysis, the effect of improved stoves is not limited to directly reducing the area deforested as a result fuel wood consumption, but through generally raising income levels.

The hypothesis that in the fuel wood market demand and supply parameters are relatively small has been confirmed by the results stated in this chapter. The reasons for low income and price elasticities have been adequately examined in the previous chapters, therefore, the following discussion is devoted to the supply elasticity of fuel wood. This parameter is especially important because it is the source of large price effects.

The fuel wood market in The Sudan - like many other markets there and in other less developed countries - is

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[21] The movement from wood to charcoal in rural areas is usually taken to indicate growing scarcity of wood resources that leads to commercialization of wood resources through charcoal production. For some consumers it is more economical to buy charcoal or firewood in the market and utilize the time that it would otherwise take to collect firewood for some income generating activity (Digernes 1977, Whitney et al 1987).

full of rigidities in production and distribution systems. Physical constraints are reflected in the fact that the present charcoal technology for example does not allow production in the rainy season. All charcoaling operations are limited to the dry season. As a result, during a significant part of the year supplies cannot be increased; and storage facilities are limited

Labor shortages are another factor that places constraints on charcoal supplies. Charcoal workers are mostly temporary part-time labors. Due to the high turn-over rate, it is not easy to assemble large numbers on demand. The share of labor costs in total charcoal production costs has risen steadily (SNEA 1987, 1991). The significance of this factor is not to be exaggerated, however, due to presence of underemployment of various forms.

Distribution of fuel wood is another area where bottlenecks are common. Transportation of both firewood and charcoal to marketing centers is constrained by the availability of fuel for trucks. Railroads are not used due to frequent delays. This is directly determined by availability of foreign exchange for different national needs. Scarcity of spare-parts, lubricants, and other inputs also contributes to transportation failure.

This factor is important because it implies that foreign exchange crunches restrict fuel wood supply at the same time they raise the demand for it due to the unavailability of modern fuels. In fact, this is one of the reasons why it was not possible to estimate demand for charcoal with LPG as one of the explanatory variables because prices of traditional and modern fuels have a tendency to move in the same direction.

Supply elasticity may be raised by influencing some of the variables enumerated above. Examples are changing the technology to allow charcoal production all year round. That will incidentally raise the efficiency of charcoal conversion. Removing transportation bottlenecks is another vital area. The caveat here is that raising supply elasticity may also reduce production costs, thereby generating another source of increases in quantities demanded via reduced prices.

Summary and Conclusions

1) In terms of effect on deforestation, improved stoves are worth pursuing. The second order effects on fuel wood consumption amount to 42% of stoves' fuel savings. The results show that the two stoves considered here, Ahfad and CES, will result in secondary purchases of fuel wood of 3% and 20% respectively. However, this depends on whether downward price adjustments are actually realized since the progress of deforestation may swamp those. Moreover, it is important to establish the source of wood or charcoal in

any area where stoves are contemplated since the qualitative nature of wood removal is critical.

2) In order to raise the effectiveness of improved stoves in slowing deforestation, the systems by which fuel wood is delivered to households must be improved. This is so because the low supply elasticity of fuel wood leads to a large price effect, resulting in further purchases of fuel wood. The areas where supply elasticity can be influenced are production technology and transportation. This prescription, however, can be hazardous unless measures that are able to raise supply elasticity without shifting the supply curve outward, and hence increasing consumption of fuel wood, can be identified. In other words, improved stoves may be complemented by a set of measures designed to enhance their effectiveness. Pricing of the stoves themselves falls under this category.

3) Improved stoves with small efficiency improvement may not be justified as a measure to contain deforestation. The realized fuel savings from these stoves are such that they may be lost in the noise of the whole operation. For instance, the Ahfad stove realizes only 4% of its 7% design fuel savings. These can be eliminated by any number of factors, e.g., if the household opts for cooking at home more than before, or if the stove is not used properly as in some of the cases surveyed in Chapter 5.

4) As premised in this study, fuel wood elasticities are lower than unity, resulting in small quantity adjustments. This is evidenced by the finding that the price effect is relatively large. The finding that fuel wood price elasticity is relatively small implies that policy to arrest deforestation through raising fuel wood prices will have modest effects. Quantity demanded responds less than proportionately to price changes. A 10% rise in the price of fuel wood, other things being equal, reduces household consumption by 5.5%.

CHAPTER 7

CONCLUSIONS

This study has examined the role of fuel wood consumption in forest depletion and land degradation in Sub-Saharan Africa, and the efficacy of improved stove programs in that respect. The policy of improved cookstoves has been analyzed from the perspective of its impact on the demand for fuel wood by households, within a framework of the fuel wood market. The environmental effects of improved stoves, in particular their potential for reducing indoor air pollution and global emissions of greenhouse gases, have also been investigated.

The hypothesis tested in this study is that improved stoves are an effective measure to slow forest destruction in Sub-Saharan Africa. Three tests were undertaken. These are: the presence of a relationship between fuel wood consumption and forest depletion, the ability of improved stoves to improve fuel efficiency and achieve wide scale dissemination, and relatively small purchases of fuel wood as a result of savings in fuel requirements.

<u>In the final analysis the impact of improved stoves on deforestation is not so much a matter of reducing fuel wood</u>

consumption, and saving a certain forest. In broad terms, improved stoves are important agents for raising income, since poverty is finally the factor responsible for environmental degradation. The following sections summarize this document, and review the main findings and conclusions of the study and their implications for policy and future research.

Findings

Deforestation is a prevalent condition throughout less developed countries. It is driven mainly by rapid population increase and slow economic growth. An area of about 7 to 11 million hectares was being depleted annually between 1980-85. With few exceptions deforestation has accelerated since the 1970s. More recent detailed information is not available.

Research in the area of forest depletion is focused on moist tropical forests, whereas much destruction and land degradation takes place in savanna lands, and semi-arid areas. Evidence for Sub-Saharan Africa is sketchy and mostly based on extrapolation from other regions. The term deforestation is used to describe diverse phenomena, encompassing total destruction of forests and land clearance, gradual degradation, and all types of land use changes. This leads to discrepancies and confusion over the underlying factors.

Evaluation of the cost of deforestation to poor countries cannot be arrived at in broad outlines. Specific cost-benefit ratios must be established, with special attention to the ecological consequences, where irreversible outcomes may occur. Some aspects of deforestation involve considerable economic costs such as filling up of reservoirs and interruption of power generation, or damage to equipment from dust storms. These losses need to be quantified. The most prominent costs associated with forest depletion in Sub-Saharan Africa are decline in foreign exchange earnings from agriculture and tourism.

Biomass fuels provide over 50% of energy requirements in less developed countries, and 70% in Sub-Saharan Africa. Households are the main users of biomass energy. The share of biomass fuels in the energy profile of Sub-Saharan African countries declined briefly in the early 1970s signaling movement away from traditional fuels associated with economic growth. However, consumption of biomass energy expanded again due to the higher cost of modern energy and sluggish economic growth. Reliance on charcoal is particularly high within the region. Concentrated urban consumption places high pressure on surrounding forest resources. Charcoal production is more damaging to forests than firewood gathering.

The widely held opinion is that agriculture is the main factor behind deforestation. One of the reasons is that most estimates of deforestation applied to this region are based on land cleared for shifting cultivation, in addition to extrapolation from other regions where agriculture is more significant. This may be true in Asia and Latin America. However, examination of expansion in the area under cultivation in Sub-Saharan Africa reveals that agriculture cannot account for the majority of forest depletion in that region. Evidence indicates that fuel wood consumption is responsible for considerable deforestation in Sub-Saharan Africa. Thus, the connection between biomass energy consumption and forest disappearance is present.

Policy aimed at slowing deforestation has treated agriculture and fuel wood consumption separately, but as causes of forest depletion, the two factors are intimately related to one another. Improvement in agriculture raises incomes and hence reliance on traditional fuels declines. On the other hand, reduction in the cost of fuel to households increases their ability to expand agricultural output.

Encouraging substitution of traditional fuels by modern fuels frequently proposed by international aid agencies is obstructed by the burden of modern fuels in the form of foreign exchange requirements to secure energy imports. The strategy of raising fuel wood prices to restrain demand is hampered by the fact that large areas of the fuel wood market lie outside of the monetary economy. In the latter, low price elasticities also limit response to this policy.

Policy to slow forest destruction in Sub-Saharan Africa over-emphasizes reforestation. Improving the efficiency of production and utilization of wood resources through improved stoves and charcoal kilns has so far received relatively little funding in comparison to reforestation programs. The cost-effectiveness of improved stoves has been demonstrated. Advanced charcoal kilns can be found in other less developed countries, but no significant efforts to transfer that technology to Sub-Saharan Africa could be identified.

Improved stove programs face a number of difficulties in the areas of technical efficiency and large scale dissemination. The technology has improved remarkably over the last decades. However, standardization and testing procedures are lacking. The most successful programs are those that emphasize minimum modification of existing designs. Improved stoves do save fuel. However, the evidence needs to be strengthened as sometimes claims of substantial fuel savings are made without proper testing.

Improved stoves have also shown appreciable contribution in cutting the time required for cooking, as well as toxic emissions, and incidence of burns and fires. Moreover, they have also been shown to reduce greenhouse gas emissions from wood burning. Current research indicates that the greatest opportunities for reducing carbon emissions in Sub-Saharan Africa are contributed by improved stoves.

Adoption of improved stoves on a large scale is still the most challenging concern. Few programs have been successful in this area. Examples are China and Kenya. Dissemination in urban areas and reliance on the market mechanism seem to be more effective than other diffusion strategies. Stoves relying too heavily on large subsidies have not survived. The use of recycled material and involvement of informal sector artisans has greatly reduced production costs.

Improved stove programs are spread over a large number of less developed countries, sponsored by development and aid agencies, NGOs, and to a lesser extent, governments. The multiplicity of stove models being promoted creates confusion among users, and may delay the feedbacks concerning stoves' performance. In addition, the large number of agencies engaged in these programs, coupled with lack of coordination, may result in inefficient allocation of meager resources through duplication of effort.

Greenhouse emissions in Sub-Saharan Africa are currently not significant. The region contributes less than 5% of total global emissions, though its share of emissions from deforestation is 20%. West Africa has the highest total level of emissions, whereas emissions from biomass are greatest in East Africa. There is great potential, however, for higher emissions, prompted by population growth. Besides, any prospects of healthier economic growth will spur industrialization and associated use of fossil fuels. Moreover, vast tracts of primary forests are still intact in central Africa which provide an additional source of emissions from deforestation if tapped.

Second order effects of improved stoves are not large enough to undermine these programs as some authors have argued previously. Based on parameters prevailing in The Sudan, about 40% of the first order decrease in fuel wood consumption achieved by the technical improvement in traditional stoves will be directed toward purchases of fuel wood. These are lower than previous results: Murck et al (48%) and Jones (50-60%).

Thus, depending on the parameters underlying any specific fuel wood market, improved stoves have the potential of making a significant impact on forest depletion. However, simulation results show that a budget share of 20%, believed to be prevalent in Sahelian countries, raises second order effects to almost 50% of fuel savings. Therefore, measurement of the particular parameters in the area where improved stoves are contemplated is essential.

Income-induced purchases of fuel wood are relatively small amounting to less than 10% of fuel savings. The second order effect resulting from price adjustments is relatively large reaching 32% of fuel savings. This is expected based on the premise that quantity movements are small such that prices will have to bear the bulk of market adjustment. The principal factor behind large price effects is low supply elasticity. The larger the first order fuel savings achieved by an improved stove, the more sensitive are the net savings to changes in economic parameters.

On the basis of the present findings, the CES stove disseminated now in several cities in The Sudan, has the potential of saving 70,000 hectares of wood annually in the area of Khartoum. For the country at large, the number is around 550,000. These findings are based on estimates of deforestation attributed to fuel wood consumption by previous studies. Based on the parameters estimated for a cross section of countries in Sub-Saharan Africa, improved stoves are likely to produce similar results to those established for The Sudan. Income-induced reduction in fuel savings reaches 17% for Sub-Saharan Africa, and 15.6% for Burkina Faso, which has a lower income elasticity.

The fuel wood market in Sub-Saharan Africa is characterized by low elasticities, thereby resulting in limited quantity adjustments on both the demand and supply sides. In The Sudan, price, income, and supply elasticities are all below unity. So is income elasticity for other

African countries. Charcoal is a normal good in all cases. For the city of Khartoum, charcoal has an income elasticity of 0.87. Income elasticity for Sub-Saharan Africa is 0.85, whereas for Burkina Faso it is 0.78. These findings are contrary to earlier evidence showing negative income elasticity for traditional fuels in Kenya and Ghana. This is believed to reflect a return back toward traditional fuels in the region due to lower income.

Household demand for charcoal is inversely related to price, with elasticity of 0.55. This is higher than the average charcoal price elasticity used by previous authors to represent low income less developed countries. For The Sudan as a whole, price elasticity is even lower (0.25). This is taken to indicate narrower substitution possibilities on a country scale than for urban areas. Also for The Sudan, quantities of fuel wood demanded respond to prices only after a lag. LPG was found to be a complementary fuel to charcoal. This is in line with previous findings for Kenya.

The procedure of using the logarithm of supply elasticity to obtain price-induced second order effects of improved stoves yielded satisfactory results. This is desirable since analytical simplicity reduces problems of data deficiency characteristic of poor countries. The results show a difference of 8 percentage points from the previous estimate of second order effects of improved stoves in The Sudan, where it was estimated that 48% of fuel savings from a stove program would be lost through purchases of fuel wood.

Policy Implications

Improved stoves are worth pursing as a measure to help contain deforestation. However, this prescription must be supplemented by qualitative evidence on the pattern and local impact of fuel wood consumption in areas where stoves are to be introduced. For instance, the CEJ stove introduced by CARE in the Southern Region of The Sudan, and claimed to cut fuel consumption per stove by 60%, may be redundant in that area. There is no evidence of serious forest depletion in the region. The scale of deforestation in closed forests in The Sudan, which are mostly located in the South, is estimated at 4,000 hectares per year, compared to 500,000 hectares annually in open forests in the country.

Improving fuel wood production and transportation systems will raise fuel wood supply elasticity, and hence reduce second order effects of improved stoves. However, since this measure may also shift the fuel wood supply schedule outward as a result of reduction in costs, it may provide a source of increases in fuel wood purchases. Transportation is an important area for intervention for a number of reasons, including its implications for the relation between traditional and modern fuels.

For the Sahelian countries in Africa, improved stoves may be less effective due to the larger budget share of fuel wood in household budget in these countries. This means that stoves introduced there must have more stringent efficiency standards than in countries where parameters produce smaller second order effects. However, since fuel wood supply elasticity was not estimated for Sahelian countries, inference on the effect of improved stoves made here is incomplete. A large supply elasticity, resulting in small price effects may offset the large income effect caused by a large budget share.

As multi-objective policy instruments, improved stoves are desirable as part of any development strategy due to the fact that they optimize the use of meager resources in poor countries. Social and environmental benefits enumerated in this study raise the cost-effectiveness of this strategy. For aid agencies and donor nations, improved stoves offer another advantage: relative isolation from the political process.

The policy of demand restraint through raising fuel wood prices may not be highly effective, due to low price elasticity. Measures to alter fuel wood consumption are more effective if they are aimed at income, which has a stronger impact on demand.

Future Research

Research on forest depletion and land degradation in semi-arid areas in Sub-Saharan Africa is lacking. The true extent of the damage done to land and environment by fuel wood consumption is not known. Detailed regional data is critical for all deforestation policy measures, including improved stove programs. Within the region, current research is concentrated in moist forests in the equatorial belt.

In the area of traditional fuels, before any research is undertaken, major tasks have to be accomplished in data collection. Estimation of fuel wood demand and supply parameters for countries in this region is also lacking. These are essential for determining the effectiveness of stoves in slowing deforestation. At present there is no evidence of any development funds for stove programs being directed toward this end. Data on traditional industry is particularly deficient, though it is gaining in importance with continued shortage of modern fuels.

More detailed investigation of the relation between deforestation and fuel wood prices is needed. It has been argued here that since quantity adjustments in fuel wood markets are relatively limited, the progress of forest depletion over time may be more reflected in price hikes than changes in quantities of fuel wood exchanged in the market. As a result, the price effect may be overwhelmed by the progress of deforestation. Verification of this argument is extremely important since that greatly reduces second order effects of improved stoves, and consequently raises their effectiveness.

The role of greenhouse gas emissions from the household sector has received little attention, in comparison with fossil fuel burning and land use changes. This is based on the idea that most of these releases are recycled, but quantitative evidence is lacking. The literature suggests that improved stoves will be useful in this respect. Global climate change induced by forest fires in the region is another area where research is needed. Also research in the cost-benefit implications of the health effects of improved stoves is needed. Indoor air pollution in less developed countries is a neglected area.

SELECTED BIBLIOGRAPHY

SELECTED BIBLIOGRAPHY

Abakah, E.M. "Real Incomes and the Consumption of Woodfuels in Ghana: An Analysis of Recent Trends." Energy Economics. (July 1990) 12(3): 227-31.

Agarwal, B. "Why Stoves Are Resisted." Unasylva. 1983 35 (140): 22-27.

--------. Cold Hearths and Barren Slopes: The Fuel Wood Crisis in the Third World. Maryland: Riverside Co., 1986.

Akarca, A. and T.V. Long II. "On the Relationship between Energy and GNP: A Reexamination." Journal of Energy and Development. (Spring 1980): 326-31.

Alam, M. et al, Fuelwood Survey of Hyderabad. Washington, D.C.: Resources for the Future, 1983.

Albee, A. "Kanun el Jadid: The Introduction of an Improved Charcoal Cooking Stove." Appropriate Technology. 1984 11(1): 12-13.

Al-Janabi, A. "Estimating Energy Demand in OPEC Countries." Energy Economics. (April 1979): 87-92.

Allen, J.C. "Wood Energy and Preservation of Woodlands in Semi-Arid Developing Countries: The Case of Dodoma Region, Tanzania." Journal of Development Economics. (19 1985): 59-84.

--------. and Barnes, D. "The Causes of Deforestation in Developing Countries." The Annals of the Association of American Geographers. 1985 72(2): 163-84.

Al-Sahlawi, M. and R. Boyd. "Energy Demand in Developing Countries and Third World Response to Changes in the International Oil Market." Journal of Energy and Development. 1987 12(2): 225-43.

Amarasekera, R.M. "Status of Improved Woodstove Dissemination in Sri Lanka." in Stoves for People: Proceedings of the Second International Workshop on Stoves Dissemination, edited by Cáceres et al, London: Intermediate Technology Publications, 1989.

Amarullah, M. Electricity Demand in Indonesia: An Econometric Analysis. Jakarta, Indonesia: Pusat Penyelidikan Masalah Kelstanikan, 1984.

Anderson, D. "Declining Tree Stocks in African Countries." World Development. 1986 14(7): 853-63.

--------. and R. Fishwick. Fuel Wood Consumption and Deforestation in African Countries. Washington, D.C.: World Bank, 1984.

Armitage, J. and G. Schramm. "Managing the Supply of and Demand for Fuelwood in Africa." Annals of Regional Science. (November 1987): 139-71.

Arnold, J.E.M. "Wood Energy and Rural Communities." Natural Resource Forum. (3 1979): 229-52.

-------. and J. Jongma. "Fuel Wood and Charcoal in Developing Countries." Unasylva. 1977 29(118): 2-9.

Ayres, C.E. The Theory of Economic Progress, A Study of the Fundamentals of Economic Development and Cultural Change. New York: Schocken Books, 1962.

Barbier, E.B., J.C. Burgess, and A. Markandya. "The Economics of Tropical Deforestation." Ambio. (April 1990) 20(2): 55-58.

Barnes, D. "Understanding fuel-wood Prices in Developing Nations." Washington, D.C.: World Bank, Agriculture and Rural Development Department, 1986. Draft.

Baxter, D. ed. Women and the Environment in The Sudan. Papers presented at the Workshop on Women and the Environment. Khartoum: Institute of Environmental Studies, 1981.

Beijer Institute. Energy and Development in Kenya: Opportunities and Constraints. Stockholm, Sweden: Beijer Institute, 1984.

Berndt, E.R. and R. Samaniego. Residential Electricity Demand in Mexico, A Model Distinguishing Access from Consumption. Cambridge, MA: MIT Working Paper, 1416-83, 1983.

--------. and G.C. Watkins. "Demand for Natural Gas: Residential and Commercial Markets in Ontario and British Columbia." Canadian Journal of Economics. (February 1977): 98-111.

Bhatia, R. Energy and Agriculture in Developing Countries. Ottawa, Canada: Energy Research Group, 1984.

--------. "Energy Demand Analysis in Developing Countries: A Review." The Energy Journal. (8 1987): 1-33.

Bogach, V.S. Wood as Fuel: Energy for Developing Countries. N.Y.: Praeger, 1985.

Bolin, B. The Greenhouse Effect, Climatic Change, and Ecosystems. New York: Wiley, 1986.

Brown, L.R. The World Wide Loss of Crop Land. Washington, D.C.: World Watch Institute, 1978.

Cáceres, R. et al, eds. Stoves for People: Proceedings of the Second International Workshop on Stoves Dissemination. London: Intermediate Technology Publications, 1989.

Cecelski, E. "Energy Needs, Tasks and Resources in the Sahel: Relevance to Woodstoves Programmes." Geojournal. 1983 7(1): 15-23.

--------, J. Dunkerley, and W. Ramsay. Household Energy and the Poor in the Third World. Washington D.C.: Resources for the Future, 1979.

Choe, B.J. Energy Demand Prospects in Non-OPEC Developing Countries. Washington, D.C.: World Bank, 1978.

Clarke, R., ed. Wood-Stove Dissemination. Proceedings of the Conference held at Wolfheze, The Netherlands, by the International Workshop on Wood-Stoves Dissemination. London: Intermediate Technology Publications, 1985.

Cline-Cole, R.A., H.A.C. Main, and J.E. Nichole. "On Fuel Wood Consumption, Population Dynamics and Deforestation in Africa." World Development. 1990 18(4): 513-27.

Club du Sahel. Energy in the Development Strategy of the Sahel: Situation, Perspectives, Recommendations. 1978.

Danielson, A.I. "A Specification Analysis of the Demand for Petroleum Products, Coal and Natural Gas." Review of Business and Economic Research. (Winter 1977): 1-20.

Darmstadter, J. Energy in the World Economy. A Statistical Review of Trends in Output, Trade, and Consumption Since 1925. Baltimore, MD: Johns Hopkins Press, 1971.

Davidson, O.R. Energy Use Patterns: Sierra Leone. Ottawa: IDRC Manuscript Report, 103e, 1985.

De Lepeleire, G., K.K. Prasad, and P. Verhart. A Woodstove Compendium. Eindhoven, the Netherlands: Eindhoven University of Technology, 1981.

Desai, A.J. "Development and Energy Consumption." Oxford Bulletin of Economics and Statistics. (August 1978): 263-72.

DEVERS, Inc. The Socio-Economic and Environmental Context of Fuelwood Use in Rural Communities of Developing Countries: Issues and Guidelines for Community Fuelwood Programs. USAID Evaluation Special Study No. 1, Washington, D.C.: 1979.

De Vos, A. Africa, The Devastated Continent? Man's Impact on the Ecology of Africa. The Hague: The Netherlands: DR. W. Junk b.v. Publishers, 1975.

Dewees, P.A. "The Woodfuel Crisis Reconsidered: Observations on the Dynamics of Abundance and Scarcity." World Development. 1989 17(8): 1159-72.

Digernes, T.H. Wood For Fuel - Energy Crisis Implying Desertification: The Case of Bara, The Sudan. Bergen, Sweden: Bergen University, 1977.

Dunkerley, J. et al, Energy Strategies for Developing Nations. Washington, D.C.: Resources for the Future, 1981.

--------. et al. "Consumption of Fuelwood and Other Household Cooking Fuels in Indian Cities." Energy Policy. (January/February 1990): 92-99.

--------. G. Knapp, and S. Glatt. Factors Affecting the Composition of Energy Use in Developing Countries. Washington, D.C.: Resources for the Future, 1981a.

Dutt, G.S. Energy Use in Rural and Urban India. Princeton, N.J.: Center of Environmental Studies, 1978.

--------. Improved Wood Burning Cooking Stoves for LDCs. Princeton, New Jersey: Princeton University Center for Environmental Studies, 1978c. Mimeo.

Earl, D. Forest Energy and Economic Development. Oxford: Clarendon Press, 1975.

--------. Sudan Renewable Energy Project: Report on Charcoal Production. Khartoum: Energy Research Council/USAID, 1984.

Eckholm, E. The Other Energy Crisis: Firewood. Washington, D.C.: World Watch Institute, 1975.

--------. Losing Ground: Environmental Stress and World Food Prospects. New York: W.W. Norton, 1976.

El Faki, G. "The Duga Stove Experience in Sudan: Lessons Learned." in Sudan Energy Research Council, Proceedings of the Regional Workshop on the Commercialization of Improved Cookstoves, 5-8 December, 1988. Khartoum, Sudan: Renewable Energy Project. 1988.

El Hinnawi, E. and M.H. Hashmi. The State of the Environment. London: Butterworths, 1987. United Nations Environment Program.

Elkan, W. "Alternatives to Fuel Wood in African Towns." World Development. 1988 16(4): 527-33.

El Sayed, S.N.E. and M. Amin. "Improvement in the Traditional Charcoal Stove: The Development of Appropriate Technology." in Women and the Environment in The Sudan, edited by Diana Baxter, Khartoum: Institute for Environmental Studies, University of Khartoum, 1981.

Emrich, W. Handbook of Charcoal Making, the Traditional and Industrial Methods. Boston: D. Reidel Publishing Co., 1985.

Ernst, E. Fuel Consumption Among Rural Families in Upper Volta, West Africa. Ouagadougou: Peace Corps, 1977. Mimeo.

FAO. Production Yearbook. Vol. 33, 1980. Rome, Italy: FAO.

--------. Natural Resources and the Human Environment for Food and Agriculture in Africa. FAO Environment and Energy Paper No. 6, Rome: FAO, 1986.

--------. Forest Product Prices. Rome: FAO, 1988.

--------. Yearbook of Forest Products. Rome: FAO, 1989.

--------. "The Story on Stoves: Encouraging News." Ceres: The FAO Review. 1991 23(3): 47-49.

FAO/UNEP. Tropical Forest Resources Assessment Project. Africa, Asia and Tropical America. Rome: FAO, 1982.

Fernandez, J. Household Energy Use in non-OPEC Developing Countries. Santa Monica, CA: Rand Corporation, 1980. Prepared for US Department of Energy.

Fleuret, P.C. and A.K. Fleuret. "Fuel Wood Use in a Peasant Community: A Tanzanian Case Study." Journal of Developing Areas. (12 1978): 315-22.

Floor, W. M. The Energy Sector of the Sahelian Countries. The Netherlands: Ministry of Foreign Affairs, 1977.

Foley, G. "Exaggerating the Sahelian Woodfuel Problem." Ambio. 1987 16(6): 367-71.

--------. and P. Moss. Improved Cooking Stoves in Developing Countries. London: Earthscan, 1983.

--------. et al, Stoves and Trees: How Much Would a Wood Stove Save if a Wood Stove Could Save Wood. London: Earthscan, 1984.

Forests National Corporation. Improved Cooking Stoves. Khartoum: Forests National Corporation. FAO Fuelwood Development for Energy in Sudan. undated.

FRIDA. Domestic Energy in Sub-Saharan Africa: The Impending Crisis, Its Measurement and the Framework for Practical Solutions. 1980.

Fries, J. and J. Heermans. "Natural Forest Management in Semi-arid Africa: Status and Research Needs." Unasylva. 1992 43(168): 9-15.

Garg, B.M.L. "Improved Chulhas (Cookstoves) Programme in India." in Cáceres et al, 1989.

Gill, J. "Improved Stoves in Developing Countries: A Critique." Energy Policy. 1987 15(2): 135-44.

Glantz, M.H., ed. Desertification: Environmental Degradation in and Around Arid Lands. Boulder, Colorado: Westview Press, 1977.

Glapke, E. and R. Fazzolare. "Economic Demand Analysis for Electricity in West Africa." The Energy Journal. 1985 6(1): 137-44.

Gradwohl, J. and R. Greenberg. Saving the Tropical Forests. Washington, D.C.: Island Press, 1988.

Griliches, Z. and M. D. Intriligator, eds. Handbook of Econometrics, Vol 3. Amsterdam: North-Holland, 1986.

Gueye, M. and G. Madon. "Case History: The Improved Cookstoves in Senegal." Revue De L'Energie. No. 356 (September 1983): 626-642.

Hassan, R.M. and G. Hertzler. "Deforestation from the Overexploitation of Wood Resources as a Cooking Fuel: A Dynamic Approach to Pricing Energy Resources in Sudan." Energy Economics. 1988 10(2): 163-68.

Hill, L.J., R.J. Lichtman, and T.S. Wood. An Analysis of Household Energy Use in Kinshasa, Republic of Zaire: Electricity, Fuelwood, and Kerosene. Oak Ridge, TN: Oak Ridge National Laboratory, 1986. Prepared for USAID, Joint USAID/World Bank Energy Assessment.

Hoffman, L. Energy Demand in Developing Countries: Identification of Research Needs. Ottawa, Canada: Energy Research Group, 1984.

--------. and M. Mors. "Energy Demand and Structural Change in Developing Countries." in Energy and the Developing Nations, edited by P. Auer, Pergamon Press Ltd., 1981.

Hosier, R.H. "The Economics of Deforestation in East Africa." Economic Geography. (April 1988) 64(2): 121-36.

Houthakker, H. and M. Kennedy. "A Long-Run Model of the World Energy Demands and Prices." in A Comprehensive Approach to Energy Resource Decision Making, edited by B. Kursunoglo and A. Perlmutter. Cambridge, MA: Ballinger, 1979.

Howes, M. "The Dissemination of Rural Innovations: General Principles and Implications for Wood-stove Programmes." in Clarke, 1985.

Hughes-Cromwick, E.L. "Nairobi Households and their Energy Use: An Economic Analysis of Consumption Patterns." Energy Economics. (October 1985): 265-78.

Hyman, E.L. "The Economics of Improved Charcoal Stoves in Kenya." Energy Policy. (April 1986): 149-58.

International Monetary Fund. International Financial Statistics. Washington, D.C.: International Monetary Fund, 1970, 1974, 1977, 1979, 1982, 1983, 1985, 1990.

Intriligator, M.D. Econometric Models, Techniques and Applications. Englewood Cliffs, New Jersey: Prentice-Hall, 1978.

Johnson, H. and M.J. Jonhnson. Environmental Policies in Developing Countries. Berlin: E. Schmidt, 1977.

Jones, D. "Some Simple Economics of Improved Cook Stove Programs in Developing Countries." Resources and Energy. 10 (1988): 247-64.

Jones, M. et al, Energy Efficient Stoves in East Africa: An Assessment of the Kenya Ceramic JIKO (Stove) Program. Oak Ridge, Tennessee: USAID and Oak Ridge National Laboratory. A report of the Office of Energy and Technology, USAID, in cooperation with Regional Economic Development Services Office of East and Southern Africa, 1989.

Joseph, S. "An Appraisal of the Impact of Improved Wood Stove Programs." in Caceres et al, 1989.

--------. and P. Hassrick. Burning Issues - Implementing Pilot Stove Programs - A Guide for Eastern Africa. UNICEF/Intermediate Technology, 1984.

Khaled, M.S. Industrial Energy Use in Bangladesh. Honolulu: East-West Center, 1981. Working Paper, 81-17.

Knowland, W.E. and C. Ulinski. Traditional Fuels: Present Data, Past Experience, and Possible Strategies. Washington, D.C.: USAID, 1979.

--------. and V. Smil. Energy in the Developing World: The Real Energy Crisis. N.Y.: Oxford University Press, 1980.

Kormondy, E.J. International Handbook of Pollution Control. New York: Greenwood Press, 1989.

Kraft, J. and A. Kraft. "On the Relationship between Energy and GNP." Journal of Energy and Development. (Spring 1978): 401-3.

Krutilla, J.V. and A.C. Fisher, eds. The Economics of Natural Environments: Studies in the Valuation of Commodity and Amenity Resources. Baltimore: Johns Hopkins University Press, 1975.

Lance, D.E. and D.C. North. Institutional Change and American Economic Growth. London: Cambridge University Press, 1971.

Larson, B. and D.W. Bromley. "Property Rights, Externalities, and Resource Degradation, Locating the Tragedy." Journal of Development Economics. 1990 33(2): 235-62.

Leach, G. Household Energy in South Asia. London: Elsevier Applied Science, 1987.

--------. "Residential Energy in the Third World." Annual Review of Energy. (13 1988): 47-65.

Leggett, J., ed. Global Warming: The Greenpeace Report. N.Y.: Oxford, 1990.

Lindzen, R.S. "Global Warming: The Origin and the Nature of the Alleged Scientific Consensus." Cato Review of Business and Government. (Spring 1992): 87-98.

Lundgren, B. "Global Deforestation: its Causes, and Suggested Remedies." Agroforestry Systems. (3 1985): 91-5.

Macauley, M. "Fuelwood Use in Urban Areas: A Case Study of Raipur, India." The Energy Journal. (July 1989) 10(3):

Mahar, D.J. " Deforestation in Brazil's Amazon Region: Magnitude, Rate, and Causes." in Environmental Management and Economic Development, edited by Gunter Schramm and Jeremy Warford. Washington, D.C.: World Bank, 1989.

Maitani, G.P., N.M. Misra, and A.K. Mahendra "Socio-economic Factors Associated with Fuel Consumption in Rural Areas." Indian Forester. (September 1986) 112(9): 753-61.

Manibog, F.R. "Improved Cooking Stoves in Developing Countries: Problems and Opportunities." Annual Review of Energy. 9 (1984): 199-227.

Massé, R. "The Dissemination of Improved Woodstoves." in Clarke, 1985.

McGranahan, G. and M. Taylor. Urban Energy Use Patterns in Developing Countries: A Preliminary Study of Mexico City. Stony Brook, New York: Institute of Energy Research, 1977.

--------. et al. Patterns of Urban Household Energy use in Developing Countries: The Case of Nairobi. Stony Brook, New York: Institute of Energy Research, 1979.

Mekuria, G. "Ethiopia: The Dissemination of Burayu Mudstoves." in Caceres et al, 1989.

Mildeberger, E. and A. Klingshirn. "Presentation of Three Representatives of GTZ Stove Dissemination Programmes." in Cáceres et al, 1989.

Mills, R. and A.N. Toke. Energy Economics and the Environment. Englewood Cliffs: Prentice-Hall, 1985.

Mounkaila, A. "Niger: The Promotion and Dissemination of Improved Stoves." in Cáceres et al, 1989.

Muhamed Ali, T.E.H. "Some Aspects of Renewable Energy: The Supply of Fuelwood in Khartoum Province." Petroleum and Minerals. 1984: 26-28. In Arabic.

Mukhtar, M.E. "Woodfuel as a Source of Energy in Sudan." Khartoum: Forests Administration, 1978. Unpublished.

-------. Energy in The Sudan: An Overview. Khartoum: Sudan National Energy Administration, 1981.

-------. "Trends of Production and Consumption of Woodfuel in Khartoum Province and Suggested Measures for Satisfying Future Needs." Msc. Thesis. University of Khartoum, 1982.

Munasinghe, M. Energy Pricing and Demand Management. Boulder, Colorado: Westview Press, 1985.

--------. and G. Schramm, eds. Energy Economics, Demand Management, and Conservation Policy. New York: Von Nostrand Reinhold Co., 1983.

Munslow, B. et al, The Fuelwood Trap: A Study of the SADCC Region. London: Earthscan Publications, 1988.

Murck, B.W.; C.M. Dufournaud, and J.B.R. Whitney. "Simulation of a Policy Aimed at the Reduction of Wood Use in the Sudan." Environment and Planning (A). 17 (1985): 1231-42.

Myers, N. Conversion of Tropical Moist Forests. A report prepared for the Committee on Research Priorities on Tropical Biology of the National Research Council, Washington, D.C.: National Academy of Sciences, 1980.

--------. The Primary Source: Tropical Forests and Our Future. New York: W.W. Norton and Co., 1984.

--------. "Tropical Forests: Patterns of Depletion." in Tropical Rain Forests and the World Atmosphere, edited by G.T. Prance. Boulder, CO: Westview Press, 1986.

------- "Tropical Forests." in Global Warming: The Greenpeace Report, edited by Jeremy Leggett, New York: Oxford University Press, 1990.

Namuye, S.A. "Survey in Dissemination and Impact of Kenya Ceramic Jiko." in Cáceres et al, 1989.

National Academy of Science. Changing Climate. Report of the Carbon Dioxide Assessment Committee. Washington, D.C.: National Academy Press, 1983.

Newcombe, K. "Energy use in Hong Kong: Part II. Sector End-Use Analysis." Urban Ecology. (1 1975): 285-309.

--------. "Energy Use in Hong Kong: Part IV. Socioeconomic Distribution Patterns of Personal Energy Use and the Energy Slave Syndrome." Urban Ecology. (4 1979): 179-205.

New York Times. "High Ozone and Acid Rain Levels Found Over Africa's Rain Forests." June 19, 1989: 1-2.

Njorge, F.M. "An Overview of Improved Stove Dissemination Programmes in Kenya." in Cáceres et al, 1989.

Noll, S.A. Transportation Energy Conservation in Developing Countries. Washington, D.C.: Resources for the Future, 1982. Paper D-73K.

Nordhaus, W.D., ed. International Studies of the Demand for Energy. Amsterdam: North-Holland, 1975a.

--------. "The Cost of Slowing Climate Change: a Survey." The Energy Journal. 1991 12(1): 37-63.

Norman, Henry. A State-of-the-Art Report on Wood Stoves in the Sahel. Arlington, VA: VITA, 1981. Background paper No. 2.

Noronha, R. "Why is it so Difficult to Grow Fuelwood." Unasylva. 1981 33(131): 4-12.

Ogawa, Y. "Economic Activity and the Greenhouse Effect." The Energy Journal. 1991 12(1): 23-35.

Olsson, K. and A. Rapp. "Drylands Degradation in Central Sudan and Conservation for Survival." Ambio. (August 1991): 192-95.

Openshaw, K. "Wood Fuels the Developing World." New Scientist. (31 January 1974) 61(883): 271-72.

--------. "Wood Fuel - A Time for Reassessment." in Knowland and Smil, 1980.

ORNL. Greenhouse Emissions in Sub-Saharan Africa. Oak Ridge, TN: USAID, 1990.

Pachauri, R.K. "Energy and Development - A Third World Perspective." in International Energy Studies, edited by R.K. Pachauri. New York: John Wiley, 1980.

--------. "Third World Energy Policies: The Urban - Rural Divide." Energy Policy. (September 1983): 217-24.

Parikh, J.K. and G. Kromer. "Modelling Energy and Agriculture Interactions: An Application to Bangladesh." Energy, The International Journal. (10 July 1985):

The Petroleum Economist. January, 1990, February, 1991. London: Petroleum Economist.

Pinchot, G. Breaking New Ground, A Personal History of Forestry in the US. N.Y.: Harcourt Brace and Co., 1947.

Pindyck, R.S. The Structure of the World Energy Demand. Cambridge, MA: MIT Press, 1979.

--------. and D.L. Rubinfeld. Econometric Models and Economic Forecasts. New York: McGraw-Hill, 1981.

Pinto, F.M. "Project to Disseminate Smokeless Woodstoves with Ovens in the State of Paraiba." in Cáceres et al, 1989.

Pitt, M.M. "Equity, Externalities and Energy Subsidies: The Case of Kerosene in Indonesia." Journal of Development Economics. 17 (1985): 201-17.

--------. "Estimating Industrial Energy Demand with Firm Data: The Case of Indonesia. The Energy Journal. 1985a 6(2):

Platt's Oil Price Handbook and Oilmanac, 1989 Prices. New York: McGraw-Hill, 1990.

Post, M. Oak Ridge National Laboratory, Personal Communication, October 1992,

Pourgerami, A. and C.R. Hirschhausen. "Aggregate Demand for Energy and Dynamics of Energy Demand Elasticities in Non-Oil Developing Countries." Journal of Energy and Development. 1991 14(2): 237-52.

Prance, G.T., ed. Tropical Rain Forests and the World Atmosphere. Boulder, CO.: Westview Press, 1986.

Prasad, K.K. Woodburning Stoves: Their Technology, Economics, and Deployment. Geneva: International Labor Organization, 1982. World Employment Program Research Working Paper

--------. "Stove Design for Improved Dissemination." in Clarke, 1985.

Quraishi, T.A. "Residential Wood Burning and Air Pollution." International Journal of Environmental Studies. 24 (1985): 19-33.

Rahman, S.H. Econometric Modeling of Energy-Economy Interactions in Oil-Importing Developing Countries: A Test with Indiana Data. Palo Alto, CA: Electric Power Research Institute, 1982.

Ramain, P. "The Energy Demand Elasticity in Relation to Gross Domestic Product: A Relevant Question." Energy Economics. (January 1986): 29-38.

Ranatunga, M.S. and K. Shrestha. "An Overview of Improved Stove Dissemination Programmes in Nepal." in Cáceres et al, 1989.

Repetto, R. "Deforestation in the Tropics." Scientific American. (April 1990) 262(4): 36-42.

--------. and M. Gillis. eds., Public Policies and the Misuse of Forest Resources. Cambridge, UK: Cambridge University Press, 1988.

Richards, J.F. and R.P. Tucker, eds. World Deforestation in the Twentieth Century. Durham, NC: Duke University Press, 1988.

Sarin, M. "An Evaluation of the Nada Chulha System." in Caceres et al, 1989.

---------. and Ketoff, A. "CO_2 Emissions from Major Developing Countries: Better Understanding the Role of Energy in the Long Term." The Energy Journal. 1991 12(1): 161-96.

Sathaye, J. and S. Meyers. "Energy Use in Cities of the Developing Countries." Annual Review of Energy. (10 1985): 109-33.

Sawadogo, A. "Fuelwood Consumption and Improved Stoves Diffusion in Ouagadougou City." in Cáceres et al, 1989.

Schelling, T.C. "Some Economics of Global Warming." American Economic Review. (March 1992) 82(1): 1-14.

Schipper, L., S. Meyers, and J. Sathaye. Energy Demand in the Developing Countries: Toward a Better Understanding. Ottawa, Canada: Energy Research Group, 1984.

Schneider, S. Global Warming: Are we Entering the Greenhouse Century? San Francisco, CA: Sierra Club Books, 1989.

Schramm, G. and J. Warford, eds. Environmental Management and Economic Development. Washington, D.C.: World Bank, 1989.

Seiler, W. and P.T. Crutzen. "Estimates of Gross and Net Fluxes of Carbon between the Biosphere and the Atmosphere from Biomass Burning." Climatic Changes. (2 1980): 207-47.

Shaller, D.V. "The Sociology of a Stove." Unasylva. 1981 33(134): 30-33.

Shantz, H.L. "An Estimate of the Shrinkage of Africa's Tropical Forests." Unasylva. 1948 2(1): 66-7.

Siddayo, C. The Energy/GDP Relationships in Asian Developing Countries: the Implications of Technical and Demand Management Policy Changes. Geneva, 1982. Mimeo.

Smith, K. "Biomass Fuels, Air Pollution and Health." Ambio. 1985 14(415): 285.

-------. "The Dialectics of Improved Stoves." in Cáceres et al, 1989.

-------. "The Health Impact of Cookstove Smoke in Africa." in African Development Perspectives, Vol 3, edited by P. Oesterdiekhoff et al. Bremen, Germany: Universitat Bremen, 1993.

Strout, A. The Demand for Kerosene in Indonesia. Cambridge, MA: MIT, 1978. mimeo.

Sudan Department of Statistics. Household Income and Expenditure Survey, 1978-80. Khartoum: Department of Statistics, Ministry of Finance, 1982.

--------. National Income at Current and Constant Prices. Khartoum: Department of Statistics, Ministry of Finance, 1989.

--------. The Economic Survey, 1987/88. Khartoum: Department of Statistics, Ministry of Finance, 1988.

Sudan Energy Research Council. Proceedings of the Regional Workshop on the Commercialization of Improved Cookstoves, 5-8 December, 1988. Khartoum, Sudan Renewable Energy Project, 1988.

Sudan National Energy Administration. Sudan Energy Handbook. Khartoum: Ministry of Energy and Mining, 1987, 1991.

Tillman, D.A., A.J. Rossi, and W.D. Kitto. Wood Combustion: Principles, Processes and Economics. N.Y.: Academic Press, 1981.

Ulinski, C. "Senegal's Ban ak Suuf Cookstove." prepared for the USAID Workshop on Energy, Environment, and Forestry, Nairobi: USAID, December 1981.

Unasylva. "The Impact of Fuel Wood Scarcity on Dietary Patterns: Hypothesis for Research." 1990-91 41(160): 29-34.

UN. The Least Developed Countries, 1989 Report. N.Y.: UN, 1990.

UNDP/World Bank. Burkina Problemes et Choix Energetiques. Ouagadougou, Burkina Faso: World Bank, 1986.

Uri, N.D. "The Demand for Electrical Energy in Korean Industry." Energy Conversion Management. 1983 23(4): 201-10.

USAID. Proceedings of Workshop on Energy, Forestry and Environment Volume II: Discussion Papers/Case Studies. Washington, D.C.: USAID, 1981.

Veblen, T. The Place of Science in Modern Civilization. Viking Press, 1919; reprint, New York, N.Y.: Transaction Publishers, 1990.

VITA. Testing the Efficiency of Woodburning Cookstoves: Provisional International Standards. Mount Ranier, MD: Volunteers in Technical Assistance, 1983.

VITA/ITDG. Wood Conserving Cookstoves: A Design Guide. Mount. Ranier, MD: Volunteers in Technical Assistance, 1980.

Walton, J.D. Jr., A.H. Roy, and S.H. Bomar, Jr. A State of the Art Survey of Solar Powered Irrigation Pumps, Solar Cookers, and Woodburning Stoves for Use in Sub-Saharan Africa. Atlanta, GA: Engineering Experiment Station, Georgia Institute of Technology, 1978. Mimeo.

Wang, M.J. and L. He. "Background and Measures for Promoting the use of Fuelwood and Coal-saving Stoves in China." in Cáceres et al, 1989.

Westwood, S. The Case for Adopting Improved Charcoal Stoves in Rwanda. CARE International, Gituza Forestry Project, 1987.

Whitney, J.B.R. Urban Energy, Food and Water Use in Arid Regions and their Impact on Hinterlands: A Conceptual Framework. Khartoum: Institute of Environmental Studies, University of Khartoum, 1981.

------- C.M. Dufournaud, and B.W. Murck. Energy Use and the Environment in The Sudan. Toronto: University of Toronto, 1985. Project Ecoville Working Paper No. 22.

-------. "An Examination of Alternatives to Traditional Fuel Wood Use in The Sudan." Journal of Environmental Management. 25 (1987): 319-46.

Williamson, O. and S.G. Winter, eds. The Nature of the Firm, Origins, Evolution, and Development. Oxford, Oxford University Press, 1991.

Wionzeck, M.S., G. Foley, and E.A. Van Buren, eds. Energy in the Transition from Rural Subsistence. Westview Press, 1982.

Wirt, G. "The Fuel-Efficient Sudanese Cookstove." Whole Earth Review. (Summer 1991): 108-09.

Wolf, C. et al, "Oil and Energy Demand in Developing Countries in 1990." The Energy Journal. 1981 2(4): 1-24.

Wong, C.S. "Atmospheric Input of Carbon Dioxide from Burning Wood." Science. (200 1978): 197-200.

Wood, T. "Improved Woodstoves in the Sahel - A Critical Assessment." proceedings of the Workshop on Energy, Forestry and Environment, Nairobi: USAID Africa Bureau, 1982.

--------. "Case Study of Wood-Stove Dissemination in the Sahel." Presented at a wood-stove seminar , Louvain, March, 1982.

Woodwell, J.E. et al, "Global Deforestation Contribution to Atmospheric Carbon Dioxide." Science. 9 December 1983, 222(4628): 1081-86.

World Bank. Energy in the Developing Countries. Washington, D.C.: World Bank, 1980.

--------. World Development Report. Washington, D.C.: World Bank, 1981, 1987, 1991, 1992.

--------. The Energy transition in Developing Countries. Washington, D.C.: World Bank, 1983.

--------. and UNDP. Sudan Issues and Options in the Energy Sector. Washington, D.C.: World Bank, 1983.

World Commission on Environment and Development. Our Common Future. N.Y.: Oxford University Press, 1987.

World Resources Institute. Tropical Forests: A Call for Action. New York: World Resources Institute, 1985

--------. World Resources, 1987. New York: Basic Books, 1987.

--------. World Resources, 1988-89. New York: Basic Books, 1988.

--------. World Resources, 1990-91. New York: Basic Books, 1991.

Zilberfarb, B. and E.G. Adams. "The Energy-GDP Relationship in Developing Countries: Empirical Evidence and Stability Tests." Energy Economics. (October 1981): 244-48.

APPENDIX

Sudan: Vegetation, annual allowable cut, and densely populated areas.

CONVERSION FACTORS

1 km^2	=	100 hectares
1 hectare	=	2.5 acres
1 billion	=	1,000 million
1 kwh	=	3.6 Mj
1 Mt of dry fuel wood	=	3 m^3 of growing stock

Energy Content of Biomass Fuels

	TOE/Mt
Firewood	0.43
Charcoal	0.72
Crop residues	0.32

APPENDIX A-1

Household Demand for Charcoal in Khartoum 1
15:57 Monday, November 23, 1992

Model: MODEL1
Dependent Variable: LNQD

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	45.46431	22.73216	111.822	0.0001
Error	28	5.69209	0.20329		
C Total	30	51.15640			

Root MSE	0.45088	R-square	0.8887
Dep Mean	10.11898	Adj R-sq	0.8808
C.V.	4.45574		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	2.770414	0.69713771	3.974	0.0005
LNPC	1	-1.123132	0.18045270	-6.224	0.0001
LNY	1	1.284183	0.12957860	9.910	0.0001

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Var Prop INTERCEP	Var Prop LNPC	Var Prop LNY
1	2.45351	1.00000	0.0019	0.0068	0.0014
2	0.54164	2.12832	0.0076	0.0806	0.0004
3	0.00485	22.49168	0.9906	0.9126	0.9983

Yule-Walker Estimates

SSE	2.60981	DFE	27
MSE	0.09666	Root MSE	0.310901
SBC	25.42758	AIC	19.69163
Reg Rsq	0.7707	Total Rsq	0.9490
Durbin-Watson	0.6277		

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
Intercept	1	4.90139944	0.78881	6.214	0.0001
LNPC	1	-0.55147693	0.19776	-2.789	0.0096
LNY	1	0.86819050	0.14492	5.991	0.0001

Durbin-Watson D	0.697
(For Number of Obs.)	31
1st Order Autocorrelation	0.593

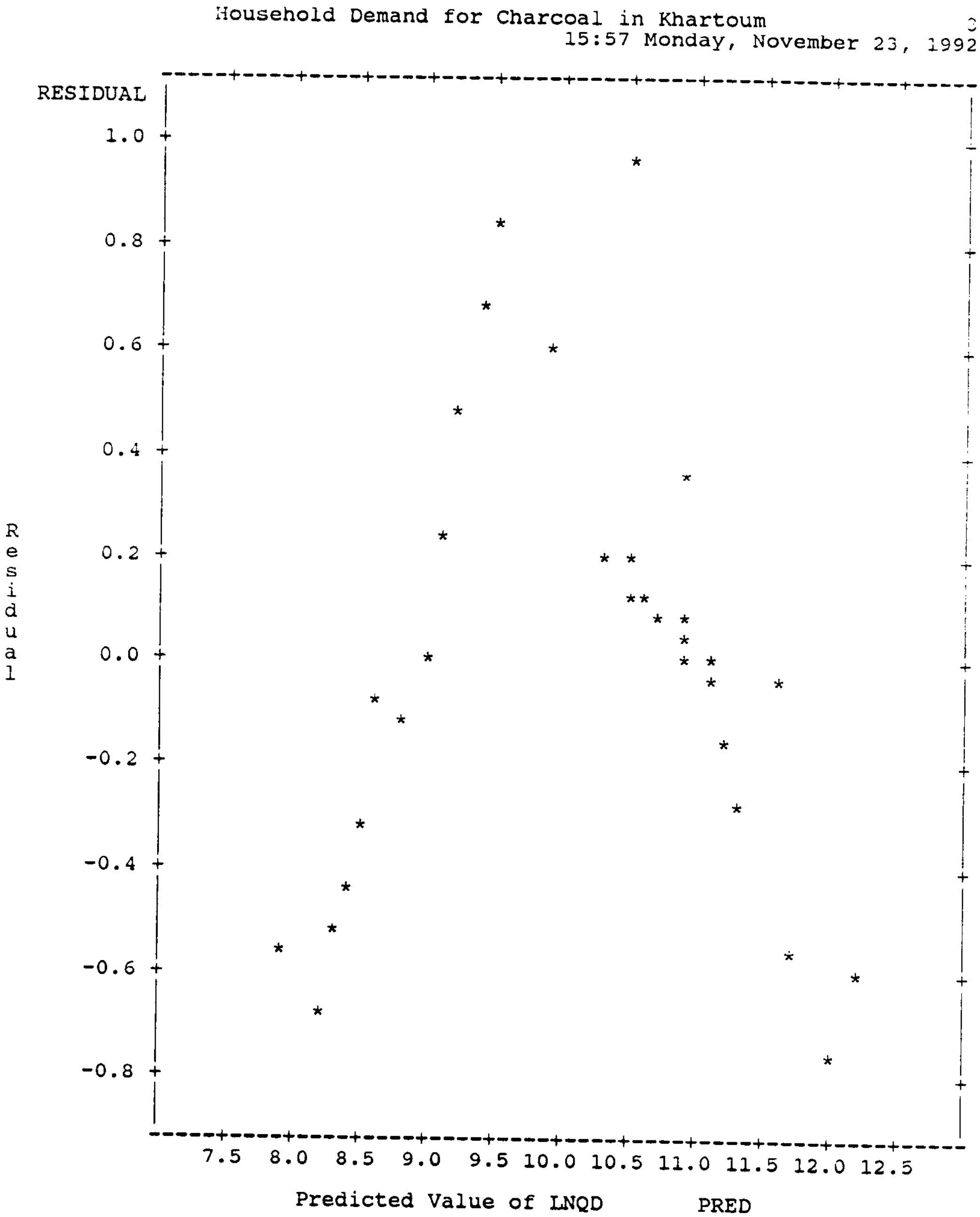

Fig. A-1 Residual Plot for Household Demand for Charcoal in Khartoum

APPENDIX A-2

Supply of Charcoal in Khartoum 1
18:17 Monday, November 23, 1992

Model: MODEL1
Dependent Variable: LNQS

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	0.12865	0.12865	74.248	0.0001
Error	7	0.01213	0.00173		
C Total	8	0.14077			

Root MSE	0.04163	R-square	0.9138
Dep Mean	12.23727	Adj R-sq	0.9015
C.V.	0.34015		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	12.088858	0.02211745	546.576	0.0001
LNPC	1	0.261747	0.03037666	8.617	0.0001

Durbin-Watson D	1.432
(For Number of Obs.)	9
1st Order Autocorrelation	0.245

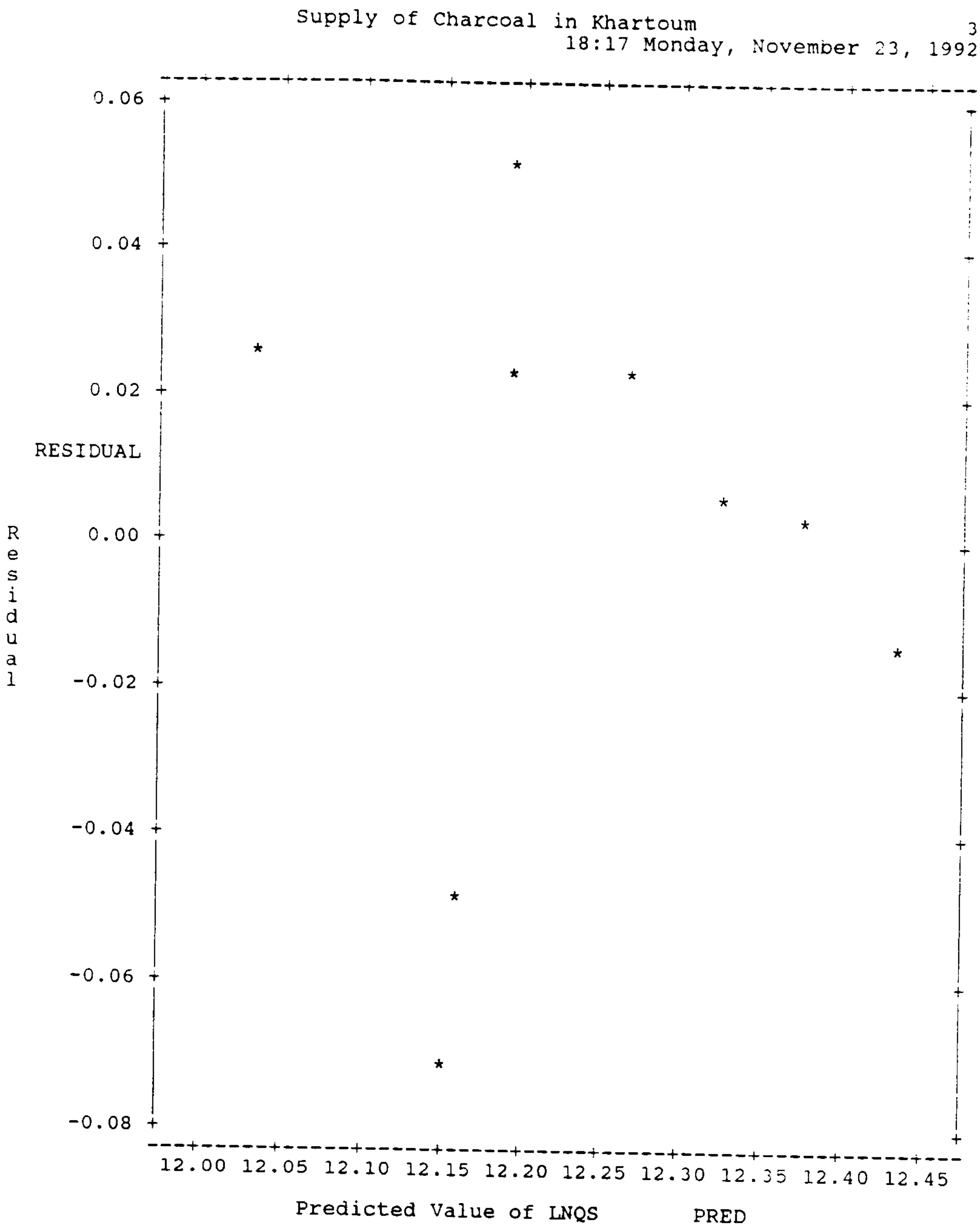

Fig. A-2 Residual Plot for Charcoal Supply in Khartoum

APPENDIX A-3

Household Demand for Charcoal in The Sudan, Lagged Price 1
18:49 Monday, November 23, 1992

Model: MODEL1
Dependent Variable: LNQD

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	9.12188	4.56094	76.299	0.0001
Error	27	1.61399	0.05978		
C Total	29	10.73586			

Root MSE	0.24449	R-square	0.8497
Dep Mean	13.44714	Adj R-sq	0.8385
C.V.	1.81819		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	8.235066	0.71064726	11.588	0.0001
LNPCL	1	-0.597051	0.13427673	-4.446	0.0001
LNY	1	0.704655	0.10024121	7.030	0.0001

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Var Prop INTERCEP	Var Prop LNPCL	Var Prop LNY
1	2.39924	1.00000	0.0006	0.0043	0.0005
2	0.59914	2.00112	0.0015	0.0537	0.0002
3	0.00163	38.41612	0.9979	0.9420	0.9993

Yule-Walker Estimates

SSE	0.701675	DFE	26
MSE	0.026987	Root MSE	0.164279
SBC	-13.5136	AIC	-19.1183
Reg Rsq	0.7268	Total Rsq	0.9346
Durbin-Watson	0.6894		

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
Intercept	1	10.0588819	0.70085	14.353	0.0001
LNPCL	1	-0.2510390	0.12669	-1.981	0.0582
LNY	1	0.4400867	0.09800	4.491	0.0001

Durbin-Watson D	0.552
(For Number of Obs.)	30
1st Order Autocorrelation	0.580

Household Demand for Charcoal in The Sudan, Lagged Price 3
18:49 Monday, November 23, 1992

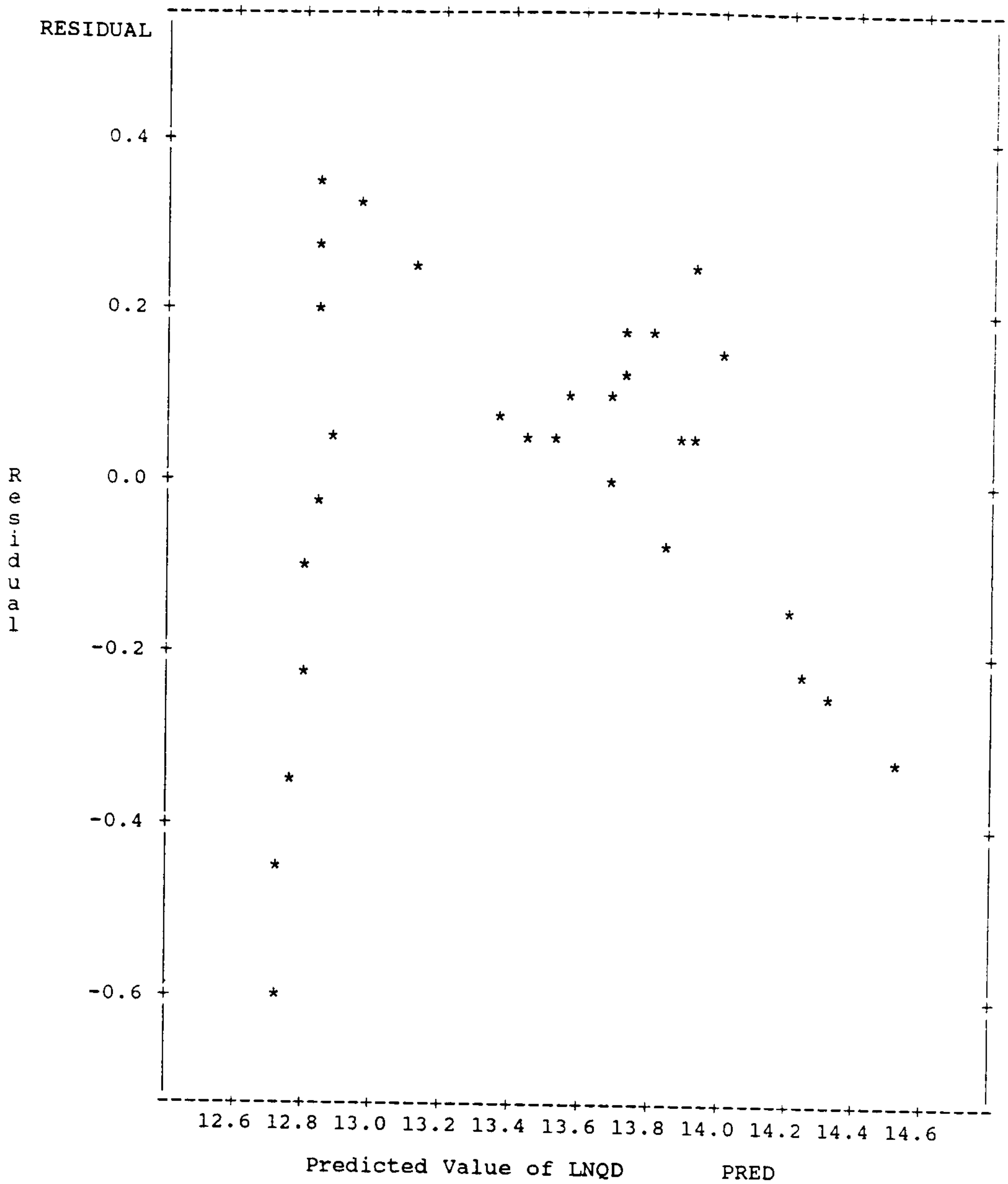

Fig. A-3 Residual Plot for Household Demand in The Sudan

APPENDIX A-4

Regional Demand for Charcoal in The Sudan 1
19:08 Monday, November 23, 1992

Model: MODEL1
Dependent Variable: LNQD

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	2.98822	2.98822	17.484	0.0086
Error	5	0.85457	0.17091		
C Total	6	3.84279			

Root MSE	0.41342	R-square	0.7776
Dep Mean	12.01701	Adj R-sq	0.7331
C.V.	3.44026		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	29.887139	4.27660649	6.989	0.0009
LNPC	1	-4.032240	0.96433500	-4.181	0.0086

Durbin-Watson D	2.103
(For Number of Obs.)	7
1st Order Autocorrelation	-0.335

APPENDIX A-5

Demand for Charcoal in Africa 1980 1
19:23 Monday, November 23, 1992

Model: MODEL1
Dependent Variable: LNQD

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	12.71892	6.35946	8.440	0.0250
Error	5	3.76749	0.75350		
C Total	7	16.48641			

Root MSE	0.86804	R-square	0.7715
Dep Mean	5.26566	Adj R-sq	0.6801
C.V.	16.48496		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	0.497408	3.75420221	0.132	0.8998
LNPC	1	-1.180788	0.59445801	-1.986	0.1037
LNY	1	1.309835	0.33297377	3.934	0.0110

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Var Prop INTERCEP	Var Prop LNPC	Var Prop LNY
1	2.98666	1.00000	0.0007	0.0011	0.0013
2	0.00895	18.26704	0.0134	0.4197	0.7760
3	0.00439	26.07017	0.9859	0.5793	0.2227

Durbin-Watson D	1.491
(For Number of Obs.)	8
1st Order Autocorrelation	0.191

APPENDIX A-6

Demand for Charcoal in Africa, 1980 1
19:19 Monday, November 23, 1992

Model: MODEL1
Dependent Variable: LNQD

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	20.45987	20.45987	17.202	0.0006
Error	18	21.40861	1.18937		
C Total	19	41.86847			

Root MSE	1.09058	R-square	0.4887
Dep Mean	4.55582	Adj R-sq	0.4603
C.V.	23.93821		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-2.288130	1.66803335	-1.372	0.1870
LNY	1	0.848277	0.20452391	4.148	0.0006

Durbin-Watson D	0.971
(For Number of Obs.)	20
1st Order Autocorrelation	0.451

Yule-Walker Estimates

SSE	16.49773	DFE	17
MSE	0.970455	Root MSE	0.985117
SBC	62.12145	AIC	59.13425
Reg Rsq	0.6350	Total Rsq	0.6060
Durbin-Watson	1.6358		

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
Intercept	1	-2.39300126	1.3240	-1.807	0.0884
LNY	1	0.85744801	0.1577	5.438	0.0001

Demand for Charcoal in Africa 1980 3
19:23 Monday, November 23, 1992

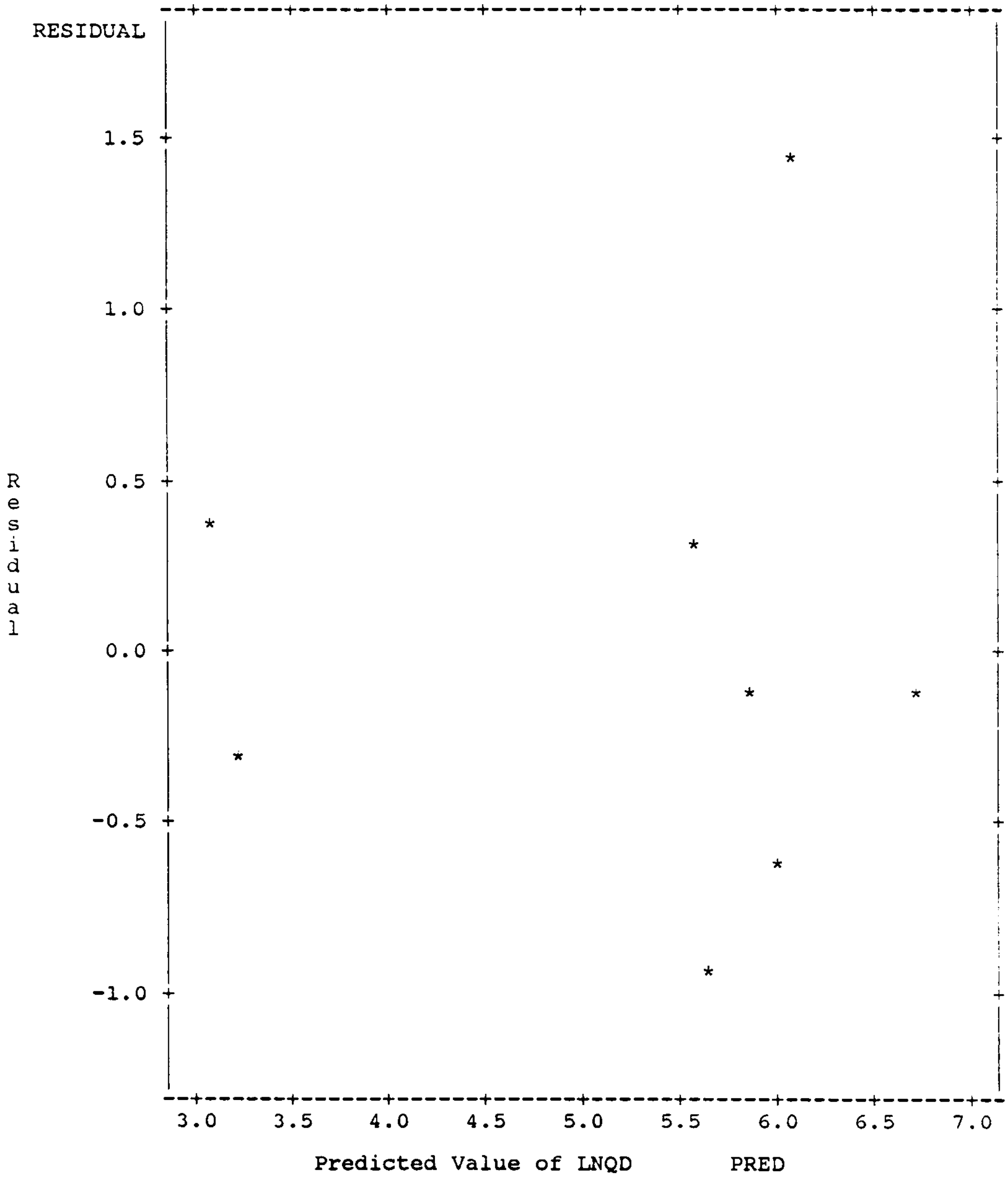

Fig. A-4 Residual Plot for Demand for Charcoal in Africa

APPENDIX A-7

Household Demand for Charcoal in Burkina Faso 1
11:27 Tuesday, November 24, 1992

Model: MODEL1
Dependent Variable: LNQD

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	0.33613	0.16806	60.772	0.0003
Error	5	0.01383	0.00277		
C Total	7	0.34995			

Root MSE	0.05259	R-square	0.9605
Dep Mean	12.02916	Adj R-sq	0.9447
C.V.	0.43717		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	7.359001	0.49341170	14.915	0.0001
LNPC	1	-0.018520	0.16843912	-0.110	0.9167
LNY	1	0.776695	0.08436096	9.207	0.0003

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Var Prop INTERCEP	Var Prop LNPC	Var Prop LNY
1	2.99824	1.00000	0.0002	0.0001	0.0001
2	0.0009609	55.85888	0.9144	0.0521	0.4623
3	0.0007955	61.39173	0.0855	0.9477	0.5376

APPENDIX A-8

Household Demand for Charcoal in Khartoum, with LPG 1
11:33 Tuesday, November 24, 1992

Model: MODEL1
Dependent Variable: LNQD

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	46.76807	15.58936	95.916	0.0001
Error	27	4.38833	0.16253		
C Total	30	51.15640			

Root MSE	0.40315	R-square	0.9142
Dep Mean	10.11898	Adj R-sq	0.9047
C.V.	3.98411		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	3.058295	0.63157908	4.842	0.0001
LNPC	1	-0.746997	0.20897713	-3.575	0.0013
LNPG	1	-0.578558	0.20427497	-2.832	0.0086
LNY	1	1.288795	0.11587427	11.122	0.0001

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Var Prop INTERCEP	Var Prop LNPC	Var Prop LNPG	Var Prop LNY
1	3.34745	1.00000	0.0009	0.0025	0.0044	0.0007
2	0.61313	2.33659	0.0089	0.0265	0.0072	0.0011
3	0.03464	9.83019	0.0009	0.3117	0.9727	0.0194
4	0.00478	26.45221	0.9893	0.6593	0.0158	0.9788

Yule-Walker Estimates

SSE	1.668177	DFE	26
MSE	0.064161	Root MSE	0.2533
SBC	15.18309	AIC	8.013152
Reg Rsq	0.7884	Total Rsq	0.9674
Durbin-Watson	0.7988		

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
Intercept	1	4.84380734	0.73647	6.577	0.0001
LNPC	1	-0.31582544	0.17085	-1.849	0.0759
LNPG	1	-0.49231428	0.18166	-2.710	0.0118
LNY	1	0.92832312	0.14304	6.490	0.0001

Durbin-Watson D	0.542
(For Number of Obs.)	31
1st Order Autocorrelation	0.683

APPENDIX A-9

Household Demand for Charcoal in The Sudan, with LPG 1
19:57 Tuesday, November 24, 1992

Model: MODEL1
Dependent Variable: LNQD

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	9.22392	3.07464	52.873	0.0001
Error	26	1.51195	0.05815		
C Total	29	10.73586			

Root MSE	0.24115	R-square	0.8592
Dep Mean	13.44714	Adj R-sq	0.8429
C.V.	1.79329		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	8.318892	0.70376910	11.820	0.0001
LNPCL	1	-0.465084	0.16572477	-2.806	0.0094
LNPG	1	-0.186423	0.14073233	-1.325	0.1968
LNY	1	0.708692	0.09891586	7.165	0.0001

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Var Prop INTERCEP	Var Prop LNPCL	Var Prop LNPG	Var Prop LNY
1	3.28816	1.00000	0.0003	0.0018	0.0034	0.0002
2	0.68473	2.19138	0.0020	0.0186	0.0050	0.0005
3	0.02550	11.35648	0.0014	0.3318	0.9891	0.0065
4	0.00162	45.02628	0.9963	0.6478	0.0025	0.9928

Yule-Walker Estimates

SSE	0.622831	DFE	25
MSE	0.024913	Root MSE	0.157839
SBC	-13.6407	AIC	-20.6466
Reg Rsq	0.7332	Total Rsq	0.9420
Durbin-Watson	0.7433		

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
Intercept	1	9.99523177	0.69928	14.294	0.0001
LNPCL	1	-0.16553303	0.13216	-1.253	0.2220
LNPG	1	-0.16022041	0.12753	-1.256	0.2206
LNY	1	0.46266995	0.10080	4.590	0.0001

Durbin-Watson D	0.497
(For Number of Obs.)	30
1st Order Autocorrelation	0.606

APPENDIX A-10

Household Demand for Charcoal in The Sudan, Current Price 1
19:54 Tuesday, November 24, 1992

Model: MODEL1
Dependent Variable: LNQD

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	10.37090	5.18545	58.224	0.0001
Error	28	2.49370	0.08906		
C Total	30	12.86460			

Root MSE	0.29843	R-square	0.8062
Dep Mean	13.39929	Adj R-sq	0.7923
C.V.	2.22721		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	8.207891	0.86136338	9.529	0.0001
LNPC	1	-0.534331	0.15257756	-3.502	0.0016
LNY	1	0.710537	0.12393397	5.733	0.0001

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Var Prop INTERCEP	Var Prop LNPC	Var Prop LNY
1	2.42872	1.00000	0.0006	0.0040	0.0005
2	0.56971	2.06473	0.0016	0.0506	0.0002
3	0.00157	39.33292	0.9978	0.9454	0.9993

Yule-Walker Estimates

SSE	0.849625	DFE	27
MSE	0.031468	Root MSE	0.177391
SBC	-9.3075	AIC	-15.0435
Reg Rsq	0.6747	Total Rsq	0.9340
Durbin-Watson	0.5063		

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
Intercept	1	10.4954139	0.72126	14.551	0.0001
LNPC	1	-0.1345234	0.12485	-1.077	0.2908
LNY	1	0.3722038	0.10249	3.632	0.0012

Durbin-Watson D	0.428
(For Number of Obs.)	31
1st Order Autocorrelation	0.621

APPENDIX A-11

Household Demand for Fuel Wood in Khartoum 1
12:11 Tuesday, November 24, 1992

Model: MODEL1
Dependent Variable: LNQDF

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	31.57231	15.78616	64.124	0.0001
Error	28	6.89306	0.24618		
C Total	30	38.46537			

Root MSE	0.49617	R-square	0.8208
Dep Mean	11.30106	Adj R-sq	0.8080
C.V.	4.39044		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	2.911429	1.22579069	2.375	0.0246
LNPF	1	-1.347512	0.28558764	-4.718	0.0001
LNY	1	1.430380	0.21665283	6.602	0.0001

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Var Prop INTERCEP	Var Prop LNPF	Var Prop LNY
1	2.32929	1.00000	0.0008	0.0031	0.0007
2	0.66868	1.86640	0.0021	0.0339	0.0001
3	0.00203	33.89579	0.9971	0.9630	0.9992

Yule-Walker Estimates

SSE	2.113435	DFE	27
MSE	0.078275	Root MSE	0.279777
SBC	19.04608	AIC	13.31013
Reg Rsq	0.6723	Total Rsq	0.9451
Durbin-Watson	0.4656		

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
Intercept	1	6.95955191	1.0297	6.759	0.0001
LNPF	1	-0.39098949	0.2356	-1.660	0.1085
LNY	1	0.69396733	0.1805	3.844	0.0007

Durbin-Watson D	0.549
(For Number of Obs.)	31
1st Order Autocorrelation	0.668

APPENDIX A-12

Household Demand for Fuel Wood in The Sudan 1
14:51 Wednesday, November 25, 1992

Model: MODEL1
Dependent Variable: LNQDF

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	2.51338	1.25669	17.545	0.0001
Error	27	1.93397	0.07163		
C Total	29	4.44735			

Root MSE	0.26763	R-square	0.5651
Dep Mean	14.76786	Adj R-sq	0.5329
C.V.	1.81228		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	12.258840	1.47800403	8.294	0.0001
LNPFL	1	-0.224580	0.25250485	-0.889	0.3816
LNY	1	0.328015	0.20071853	1.634	0.1138

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Var Prop INTERCEP	Var Prop LNPFL	Var Prop LNY
1	2.26421	1.00000	0.0002	0.0012	0.0002
2	0.73532	1.75477	0.0003	0.0157	0.0000
3	0.0004713	69.31372	0.9995	0.9831	0.9998

Yule-Walker Estimates

SSE	0.540424	DFE	26
MSE	0.020786	Root MSE	0.144172
SBC	-21.0996	AIC	-26.7044
Reg Rsq	0.4386	Total Rsq	0.8785
Durbin-Watson	0.8093		

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
Intercept	1	13.4284311	0.86915	15.450	0.0001
LNPFL	1	-0.00304369	0.14358	-0.021	0.9832
LNY	1	0.1583807	0.11686	1.355	0.1870

Durbin-Watson D	0.187
(For Number of Obs.)	30
1st Order Autocorrelation	0.694

APPENDIX A-13

Household Demand for Firewood in Khartoum

13:34 Tuesday, November 24, 1992 1

Model: MODEL1
Dependent Variable: LNQDF

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	24.62122	12.31061	26.993	0.0001
Error	28	12.77003	0.45607		
C Total	30	37.39124			

Root MSE	0.67533	R-square	0.6585
Dep Mean	10.67751	Adj R-sq	0.6341
C.V.	6.32480		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	4.670077	3.44772537	1.355	0.1864
LNPF	1	-0.607299	0.62139990	-0.977	0.3368
LNY	1	0.946972	0.55116545	1.718	0.0968

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Var Prop INTERCEP	Var Prop LNPF	Var Prop LNY
1	2.07197	1.00000	0.0002	0.0005	0.0002
2	0.92749	1.49464	0.0002	0.0095	0.0000
3	0.0005372	62.10641	0.9996	0.9900	0.9998

Yule-Walker Estimates

SSE	1.15713	DFE	27
MSE	0.042857	Root MSE	0.207019
SBC	1.127048	AIC	-4.6089
Reg Rsq	0.5005	Total Rsq	0.9691
Durbin-Watson	0.6242		

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
Intercept	1	7.92687833	1.1719	6.764	0.0001
LNPF	1	-0.02993611	0.2056	-0.146	0.8853
LNY	1	0.38258728	0.1826	2.096	0.0456

Durbin-Watson D	0.102
(For Number of Obs.)	31
1st Order Autocorrelation	0.860

APPENDIX A-14

KHARTOUM DATA

Year	Charcoal Consumption TOE	Price of Charcoal Ls/sack	Price of LPG Ls/bot	Fuel Wood Consumption TOE	Fuel Wood Price Ls/sack	GDP Ls Million
1960	1591.60	0.64	1.39	6920	0.38	38
1961	1943.28	0.64	1.39	8097	0.38	48
1962	2345.40	0.64	1.39	9732	0.38	49
1963	2922.48	0.65	1.39	11880	0.39	55
1964	3713.75	0.67	1.53	14855	0.41	62
1965	4898.05	0.68	1.53	19347	0.42	66
1966	6260.30	0.70	1.53	25657	0.45	83
1967	8385.30	0.70	1.53	34650	0.46	95
1968	11437.20	0.70	1.53	47655	0.47	101
1969	16474.90	0.72	1.53	66700	0.49	114
1970	23340.00	0.75	1.53	93360	0.52	133
1971	32257.60	0.80	1.53	120815	0.62	159
1972	34244.37	0.85	1.53	124525	0.71	216
1973	36959.04	0.90	1.53	128330	0.76	324
1974	38852.10	1.00	1.53	132150	1.06	400
1975	42215.80	1.30	1.53	136180	1.52	500
1976	45664.45	1.50	1.53	140075	1.69	632
1977	49757.62	1.75	1.53	144225	1.81	807
1978	52717.50	2.00	1.53	148500	2.00	1004
1979	55044.00	2.40	1.53	152900	2.32	1181
1980	58249.10	3.00	3.10	157430	2.75	1442
1981	60686.20	3.00	3.27	161400	3.00	1819
1982	62641.00	3.50	3.44	166600	3.27	2331
1983	64946.00	5.00	7.19	172500	4.12	2609
1984	67157.00	6.00	11.42	178514	5.00	3247
1985	70381.00	9.00	13.92	187082	9.50	7383
1986	73759.00	10.00	13.92	196062	10.50	9564
1987	77300.00	35.00	13.92	205473	30.00	12490
1988	99778.00	91.67	13.92	252473	68.33	22069
1989	103666.00	80.00	38.92	263042	65.00	44491
1990	108564.00	93.00	50.00	275042	77.50	80000

APPENDIX A-15

KHARTOUM DATA 5
13:34 Tuesday, November 24, 1992

OBS	Year	Firewood Consumption TOE	Price of Firewood Ls/Kantar	GDP Ls Million
1	1960	3845	0.13	38
2	1961	4441	0.13	48
3	1962	5330	0.13	49
4	1963	6359	0.14	55
5	1964	7862	0.15	62
6	1965	10185	0.16	66
7	1966	13826	0.20	83
8	1967	18857	0.21	95
9	1968	26939	0.22	101
10	1969	37630	0.25	114
11	1970	53694	0.26	133
12	1971	69600	0.30	159
13	1972	70735	0.45	216
14	1973	71852	0.56	324
15	1974	74445	0.62	400
16	1975	75269	1.12	500
17	1976	76390	1.75	632
18	1977	77149	1.87	807
19	1978	78821	2.00	1004
20	1979	81037	2.25	1181
21	1980	83521	2.50	1442
22	1981	84872	3.00	1819
23	1982	87597	3.04	2331
24	1983	90606	3.25	2609
25	1984	93822	4.00	3247
26	1985	95516	10.00	7383
27	1986	99635	11.00	9564
28	1987	103668	25.00	12490
29	1988	124567	45.00	22069
30	1989	130035	50.00	44491
31	1990	136689	62.00	80000

OBS	YEAR	Supply of Charcoal Tons	Price of Charcoal Ls/sack
1	1972	172270	0.80
2	1973	175808	1.25
3	1974	181506	1.30
4	1975	202640	1.50
5	1976	208418	1.50
6	1977	218395	2.00
7	1978	227213	2.50
8	1979	237785	3.00
9	1980	247488	3.75

APPENDIX A-16

SUDAN DATA

year	Consumption of Charcoal TOE	Price of Charcoal Ls/sack	Price of LPG Ls/bot	Consumption of Fuel Wood TOE	Fuel Wod Price Ls/sack	Sudan GDP Ls million
1960	157000	0.64	1.39	624000	0.38	376.2
1961	184200	0.64	1.39	774000	0.38	402.6
1962	215000	0.64	1.39	975000	0.38	408.1
1963	246000	0.65	1.39	1300000	0.39	421.7
1964	284000	0.67	1.53	1680000	0.41	442.2
1965	322000	0.68	1.53	1890000	0.42	456.9
1966	363044	0.70	1.53	2250000	0.45	489.9
1967	407000	0.70	1.53	2370000	0.46	527.0
1968	453400	0.70	1.53	2450000	0.47	505.9
1969	502810	0.72	1.53	2600000	0.49	516.6
1970	543575	0.75	1.53	2630000	0.52	531.7
1971	590200	0.80	1.53	2670000	0.62	637.4
1972	639100	0.85	1.53	2700000	0.71	832.4
1973	688000	0.90	1.53	2710000	0.76	1246.2
1974	737000	1.00	1.53	2720000	1.06	1510.8
1975	786000	1.30	1.53	2730000	1.52	1848.0
1976	835000	1.30	1.53	2740000	1.69	2339.7
1977	880000	1.30	1.53	2750000	1.81	2882.7
1978	925000	2.00	1.53	2770000	2.00	3462.0
1979	968000	2.40	1.53	2790000	2.32	4072.1
1980	1025000	3.00	3.10	2990000	2.75	4972.0
1981	1070000	3.00	3.27	3050000	3.00	6063.0
1982	1115500	3.50	3.44	3200000	3.27	7521.0
1983	1150000	5.00	7.19	3330000	4.12	8996.0
1984	1192862	6.00	11.42	3404078	5.00	10822.0
1985	1225452	9.00	13.92	3495929	9.50	23070.8
1986	1259001	10.00	13.92	3590466	10.50	29887.0
1987	1293541	35.00	13.92	3687757	30.00	40291.0
1988	1394361	91.67	13.92	4035704	68.33	73563.0
1989	1430975	80.00	38.92	4138794	65.00	148302.0
1990	1471537	89.00	50.00	4255782	77.50	305000.0

Region	Households Consumption of Charcoal TOE	Price of Charcoal Ls/sack
Northern	48195	121.67
Eastern	196115	82.67
Khartoum	108564	85.00
Central	401392	74.67
Kordofan	287968	74.00
Darfour	346351	74.00
Southern	82952	85.00

APPENDIX A-17

AFRICA DATA

Country	Consumption of Charcoal 000 TOE	GDP $ million
Benin	8.47	1087.69
Burk.Fas	17.87	1400.99
Burundi	18.12	960.90
Iv.Coast	110.60	9840.57
Ethiopia	80.16	4106.28
Ghana	306.80	14907.27
Kenya	726.30	6955.87
Liberia	73.36	916.60
Malawi	166.05	1354.32
Mauritan	17.34	689.29
Nigeria	220.16	80148.15
Rwanda	10.08	1163.29
Senegal	117.53	2846.77
Sier.Leo	36.44	1091.12
Sudan	1782.92	8144.20
Tanzania	361.00	4975.19
Togo	31.72	1058.01
Uganda	180.52	8494.58
Zaire	429.90	5764.49
Zambia	216.24	3752.18

Country	Consumption of Charcoal 000 TOE	Price of Charcoal US$/Mt	GDP US$ million
Burundi	18.12	205.60	960.90
Ghana	306.80	455.40	14907.27
Kenya	726.30	96.60	6955.87
Sudan	1782.92	200.10	8144.20
Tanzania	361.00	170.80	4975.19
Togo	31.72	250.80	1058.01
Iv.Coast	110.60	336.00	9840.57
Zambia	216.24	87.69	3752.18

APPENDIX A-18

BURKINA DATA 5
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OBS	Year	Consumption of Charcoal Tons	Price of Charcoal CFAF/kg	GDP US$ Million
1	1981	120000	22.0	285.0
2	1982	133500	23.0	359.6
3	1983	147000	22.0	381.0
4	1984	161680	20.0	390.6
5	1985	176700	25.0	469.3
6	1986	193000	31.7	503.5
7	1987	210249	23.0	565.0
8	1988	227731	26.6	700.0

VITA

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