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Markets for Trees: An Environmental Kuznets Curve?

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Introduction*

In many developing countries, deforestation has had a major impact on both household and national economies. In parts of Africa, as much as 70-90 percent of the nation's energy usage can be traced to woody biomass (Armitage and Schramm 1989). Because heating and the ability to cook food can be as important as the food supply itself, trees are critical to the very subsistence of some peasants. Alternative energy sources, such as dung, kerosene, or oil, have high opportunity costs.

No less important are the environmental functions that trees perform. At the farm level, trees can protect and even enhance the long term productivity of land by substantially reducing soil erosion and by providing important nutrient and organic matter inputs (Young 1989). The main alternative--increased reliance on chemical fertilizers--is an unrealistic option for many poor farmers either because of cash constraints or insufficient rainfall, a necessary complement to artificial fertilizers. On the national level, the loss of trees can cause further damage, including reduced cash crop exports, increased siltation of rivers and reservoirs, and increased pressure on public lands and protected areas.

Given the importance of trees to both individual and social welfare, there has been much concern during the past two decades over declining wood stocks in developing countries. Building on projections of population growth and current per capita woodfuel consumption, a number of

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researchers have predicted a massive woodfuel "gap," or excess demand emerging in the near future (e.g., Openshaw 1978), while other observers have questioned the assumptions underlying such predictions (Dewees 1989; Leach and Mearns 1988). In addition to concern about the adequacy of fuelwood supplies, there is growing concern that stress on the agricultural resource base arising from loss of tree cover including high rates of soil erosion will cause a decline in agricultural productivity in the face of increasing population.

Such a gap between supply and demand of fuelwood, however, is only notional; markets for fuelwood can be expected to clear, although at substantially higher real prices. Physical scarcity and rising prices would normally lead to conservation and/or substitution on the consumption side and increased production on the supply side to eliminate the excess demand. Over the last thirty years, numerous studies have shown that smallholders in Africa do respond to such economic incentives (Jones 1960; Schultz 1964).

To say that smallholders respond, however, is not to say that the market will solve all problems. Market failures, such as poorly functioning factor markets and externalities, may lead to a sub-optimal adjustment by farmers to an increase in demand for fuelwood. There is evidence of both types of market failure.

Dewees (1991) argues that household capital and labor endowments affect farmers' decisions regarding whether to establish or to remove black wattle woodlots in a coffee/tea area in Kenya, implying that factor markets malfunction. He finds evidence that farmers with relatively less labor are more likely to establish woodlots, and that poorly functioning credit markets constrain cash-poor farmers from investing in more profitable cash crops. Because trees require little labor and few capital inputs, they are a good land-use option for the poorest households. Thus, contrary to the usual notion that overcoming market failure would ameliorate fuelwood shortages, Dewees argues that if capital and labor markets functioned better, farmers would replace trees with other crops.

This particular conclusion rests on the assumption that trees are relatively less profitable than other land use options. With increasing scarcity, however, wood trees are likely to become a competitive land use option, leading farmers to grow more trees (Chambers and Leach 1989;

Gustavsson and Kimeu 1991). However, even if trees become a profitable option, improperly functioning credit markets may prevent some farmers from planting more trees because of the high opportunity cost of the land prior to the accrual of wood and erosion control benefits.

The positive external economies associated with trees suggest that even if farmers respond to increased demand for fuelwood, they are unlikely to achieve the socially optimal level of tree cover. These external economies include benefits from erosion control and wind screening, as well as from reduced downstream siltation, influences on geohydrology, and on bird and animal habitats. Indeed, the erosion control benefits provide a link between energy production and sustainable agriculture.

Given these links, some analysts have expressed concern about a possible downward spiral, and resulting deleterious social costs, as population growth leads to land clearing and increases demand for woodfuel, which decreases the stock of trees and further erodes the soil. Loss of topsoil and nutrients will in turn reduce land productivity and necessitate increased land clearance for farming. By clearing more land, there will again be fewer trees and a reduced woodfuel supply. Once surplus land is exhausted, trees will be cut primarily for fuel, leading to further deterioration in the nutrient cycles involving biomass burning and declining soil productivity (Newcombe 1989). Reduced tree cover in parts of Africa is seen as evidence that this downward spiral, inimical to the long-term interests of small farmers, is indeed taking place (Cleaver and Schreiber 1992; Newcombe 1989; Leach and Mearns 1988).

Other evidence is more hopeful. For a number of environmental and natural resource indicators, recent cross-country data suggest that as per capita income increases, the level of degradation first increases, but then reaches a maximum and subsequently decreases (Grossman and Krueger 1991; World Bank 1992; Seldon and Song 1994). The pattern thus forms an inverted "U" similar to the relationship noted by Kuznets for income inequality (Kuznets 1955). Environmental degradation and income inequality can both be seen as types of market failure that, apparently, worsen and then improve during the process of modern economic growth. The underlying causes of the degradation, and then its reversal, are obviously complex, but our interest here is whether there exist similar corrective forces that would counter the hypothesized downward spiral in tree cover, perhaps as a response to the changing level of degradation or changes in factor prices. In particular, is there an "environmental Kuznets curve," or self-correcting process that will break the downward spiral described above?[1]

If such a relation exists, the underlying processes may work in the following way. Rising population densities may lead first to the clearing of land, an expansion of agriculture, and a loss of tree cover. However, with rising land pressures, increased erosion, higher prices of fuelwood, and declining crop yields, investments that raise land productivity and produce fuelwood would have a higher return than previously. The number of on-farm trees would then increase, bringing along the associated positive externalities. Thus, the change from extensive to intensive agriculture could lead to improvements in tree cover at the same time that population densities are increasing.[2]

Previous empirical studies are inconclusive on whether observed loss of tree cover represents a downward spiral or merely an arm of an inverted "U". There are analyses of non-industrial private woodlots in North America (Clements and Jamnick 1989; Jamnick and Beckett 1988; McMahon 1964), but these studies offer only methodological guidance for the developing country context. And while studies that examine woodfuel and its relationship to soil conservation in African communities (Ngugi and Bradley 1986) do exist, few include data on household characteristics and income that would permit a careful analysis of household behavior. Indeed, few micro-level empirical studies exist on the economics of fuelwood production and markets in developing countries.

This study tests for the presence of a Kuznets curve for fuelwood using data on tree-growing among smallholders in our study sites in Kenya and Tanzania. We first use farm level data to estimate the relative profitability of fuelwood production as a competitive economic activity

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[1] The possibility of this pattern for tree cover in Kenya was first suggested by M. Norton-Griffiths, U.N. Environment Program, Nairobi (pers. comm.). Grossman & Krueger (1994) and World Bank (1992) also refer to an inverted “U” when discussing the relationship between economic growth and environmental quality. Selden and Song (1994) are the first to use the term environmental “Kuznets curve” for air pollution.

[2] This process is suggestive of the well-known Boserup (1965) hypothesis that increased population density induces a shift to more labor-intensive farming systems and confronts farmers with new possibilities for innovation. It is also consistent with recent cross-country evidence from Africa that high population density

for smallholders. Second, we test econometrically a series of hypotheses about the incentives and constraints for fuelwood production. Finally, we simulate the impact of increased population density and land subdivision on tree-growing. This simulation supports the hypothesis of a reversible process rather than a secular trend; as population density increases, the observed degradation in tree cover will reverse and begin to improve. (Of course, if the relationship is thought of in terms of "tree cover" rather than "degradation of tree cover", the "U" shape is upright and the so-called downward spiral turns upward.)

The next section describes the woodfuel portions of the survey, followed by the budget analysis and econometric model. The simulation and conclusions follow

Study Site and Survey Methods

The study villages are both characterized by long ridges and deep valleys, with slopes for the entire coffee zone in Murang'a ranging from 14-55%, and averaging 28% (Ngugi and Bradley 1986). Soils are generally well drained, very deep, dark reddish brown, slightly firm clays of high natural fertility and fairly rich organic matter contents (Jaetzold & Schmidt 1983). Given the combination of high rainfall, steep slopes, and intensive cultivation, soil erosion throughout the coffee growing zones of both countries has long been recognized as a serious problem. In one study of erosion at various locations in Murang'a, annual soil loss figures ranged from 1.5 mt/ha to 191 mt/ha (Kilewe, 1985). Even on terraced fields in the coffee zone, Kilewe (1985) measured soil losses as high as 125 mt/ha and larger.[3]

The most prevalent species of wood trees in Murang'a are black wattle, eucalyptus, Cyprus, and *Grevelia robusta.*[4] In Kirua, indigenous varieties are still prevalent; farmers planting trees, however, tend to plant *Grevelia robusta* and eucalyptus*.* In Murang'a, wood trees are grown

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and agricultural intensification are not necessarily accompanied by environmental degradation (Turner et al. 1993).

[3] For the United States, the Department of Agriculture regards 10 mt/ha as an acceptable level of erosion, but tolerable levels may be lower for tropical climates. (Young, 1989).

[4] Eucalyptus and G. robusta are from Australia.

in woodlots, on land borders, or in fields of maize and beans (Ngugi and Kabutha, 1986), while in Kirua many trees are interplanted with coffee. The Kenyan government ban on intercropping with coffee, aimed at maximizing coffee production, keeps trees out of the coffee fields there. Over the past twelve years, the households in the survey sample have added an average of 4.5 trees to their farms, while farmers in Kirua have had no net change in the number of trees. The market for wood--fuelwood, poles (for buildings and fences), or live trees--is well developed and very active in Murang'a: 85% of the households report at least one purchase or sale of wood within the last three years, and 70% have been involved in an exchange within the last four months. Many farmers noted that wood prices have been rising rapidly, and the survey data show that fuelwood expenditures can be substantial. Fuelwood prices have gone up much less in Kirua. Although average cash expenditures on wood are only about 2% of total expenditures, if a household had to buy all of its fuelwood at local prices wood expenditures would constitute about 10% of total expenditures.[5]

The household tree planting decision

Small farmers in rural areas of Africa engage in a wide variety of activities, diversifying income sources in a particularly risky environment. So farmers may plant trees even if the expected return to trees is less than that to other possible uses of the land. But on the margin, improvements in the profitability of any crop will increase the land allocated to it. If the profitability of trees improves relative to the major crops, coffee and maize, tree planting is likely to increase.

In deciding whether or not to plant wood trees, a farmer will compare the benefits and costs of tree growing with those of maize and coffee, the predominant subsistence and cash crops in the study area. Table 9.1 presents net present values (NPVs) of these costs and benefits based on crop budgets compiled by Patel (1993). These NPVs are calculated over one six-year cycle of growth of G. robusta and an equivalent period of time for annual maize and existing coffee, using

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[5] Based on field sampling of wood bundles and self-reported purchases, it is estimated that an average family of six uses 3 firewood bundles daily (4.5 kg each, black wattle), priced at 3 Ksh each. This estimate is consistent with the widely assumed consumption figure in Africa of 1 m^3 per capita (1 m^3 = 710 to 1000 kg, depending on assumed moisture content and density).

prices and wages from Murang'a and yields from a similar agro-economic zone in nearby Nyeri District (Sellen et al, 1995).[6] We did not have access to similar crop budgets for the Tanzanian study site. Erosion rates were estimated using the universal soil loss equation (Wischmeier and Smith 1978) with parameters suggested by Young and Muraya (1990). Costs of erosion are calculated through the fertilizer replacement cost approach (Kim and Dixon, 1986). Maize is assumed to be planted among the young trees for the first three years of establishment. Given the prevailing casual labor wage rate of Ksh 24/day, the prevailing price of fuelwood of Ksh 900/m^3, and a discount rate of 12.5%, trees produce only one-half the net present value of existing coffee, but produce about 10% more value than annual maize plantings. This result is especially noteworthy because it contrasts with earlier studies that assumed coffee, tea, and annual crops to be significantly more profitable than trees (World Bank, 1986), a conclusion challenged by Chambers and Leach (1989). The primary reason for the differences in these assessments is rising fuelwood prices over the period under consideration, and the absence of erosion costs in the earlier estimates. A recent analysis by Gustavsson and Kimeu (1991) finds that in the highlands of Kakamega District in western Kenya, an area similar to the one studied here, smallholder eucalyptus woodlots are more profitable than maize and would outperform tea if tea prices dropped by 25 percent.

This analysis, based on an average or representative household, may disguise differences in profitability arising due to individual household characteristics and resource endowments. For example, given poorly functioning rural credit markets, households are likely to face different shadow prices for the capital required to make the initial investments in tree growing. Individual rates of time preference too may vary depending upon the age composition of the household and other factors, thereby leading to a difference in the discount rate for different households. Shadow wage rates also may vary by household. Although households may face the same casual labor

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[6] Establishing coffee is not a viable option. Given prices prevailing in 1992, the net present value of establishing coffee is negative over any reasonable combination of discount rates, length of time period, and labor costs. Establishing coffee was quite profitable, however, in the sixties and late seventies, when world and domestic prices were much higher.

markets, failures in these markets -- particularly wage stickiness -- constrain the ability of the household to hire or sell casual labor. Moreover, to the extent that labor skill levels differ across households, the opportunities for off-farm employment for some will alter the opportunity costs. Finally, prices for fuelwood have increased rapidly in real terms in recent years; this may lead some farmers to expect that prices at harvest time--five to six years after planting--may be considerably higher than present prices.

Table 9.1 thus includes sensitivity analysis to the assumed shadow wage, the discount rate, and the price of trees in order to show how different types of households may perceive the relative profitability of tree-growing. The general pattern is that trees become relatively more profitable at lower discount rates and higher wage rates. Existing coffee is more profitable than trees in every case except the combination of the highest shadow wage rate, the lowest discount rate, and a price for wood double the price in 1992. There consequently is no incentive to uproot coffee and plant trees. On the other hand, trees are quite competitive with maize. With prices for fuelwood 50% higher than those prevailing in 1992, trees are more profitable than maize under any combination of discount rates and wage rates. With the 1992 fuelwood price of 900 Ksh /m^3, trees are more profitable at discount rates of 12.5% and lower; at higher discount rates trees remain competitive when shadow wages are high. The column with fuelwood prices of Ksh 700/m^3 represents the situation a few years prior to our survey. With these relative prices, trees are more profitable than maize only for those households with very low discount rates and moderate to high shadow wage rates. Thus, the situation is changing rapidly, with expectations about future prices of wood playing a key role in planting decisions.

More generally, differences across households in terms of factors and resources are likely to create variations in the relative profitability of wood trees. These differences will affect the amount of investment the household is willing to make in this activity. Which households are most likely to make these investments?

In the absence of long-term credit markets, the relevant discount rate for a household will depend on the rate of time preference, investment opportunities, and risk premium (Hoekstra,

Table 9.1. Relative profitability of tree-growing for fuelwood

Discount Factor	Wage Ksh/Day	Existing Coffee	Maize	Wood Trees With a price per cubic meter of Ksh: 700	900	1350	1800
		(net present value, thousand 1992 Kenya shillings per hectare)					
	12	121	53	51	61	84	107
5.0%	24	106	46	48	58	81	104
	36	92	39	45	55	78	101
	12	96	43	37	44	59	75
12.5%	24	85	37	35	41	57	72
	36	73	32	32	39	54	69
	12	79	36	28	33	43	54
20.0%	24	70	31	26	31	41	51
	36	60	26	24	28	39	49
	12	63	29	21	24	30	37
30.0%	24	55	25	19	22	28	35
	36	48	22	17	20	26	33

Notes: NPV's are calculated over a six-year period, one harvesting cycle for trees. Trees are Grevelia robusta. Erosion costs are included in these calculations, assuming erosion rates for maize of 30 mt/ha, for established coffee of 4 mt/ha, and for trees of 21, 6, 2, 1, and 1 mt/ha in the first to 5th year of tree-growing. Nitrogen content of eroded sediment is assumed to be 0.005. The cost of lost nitrogen is calculated from local fertilizer prices. Maize is planted among the trees during the first three years of establishment. Daily wages for casual labor were about Ksh 24 per day in 1992; fuelwood cost about Ksh 900/cubic meter. See Patel (1993) for more details and additional calculations.

1985). We expect the personal discount rate to vary across households by income for two reasons. First, compared to poor farmers, wealthy farmers will be more willing to forgo current consumption for future benefits. Second, wealthy farmers will be more likely to assign lower risk premiums on future outcomes. Because a lower discount rate makes trees more attractive relative to other options, we expect to observe a positive relationship between tree growing activity and household income.

Given labor market imperfections and diminishing returns to labor use, the opportunity cost of labor should decrease as labor supply increases, holding land area constant. Therefore, given that trees become more attractive as the cost of labor rises, tree growing is expected to vary inversely with labor availability.

Just as there are diminishing returns to labor, there are likely diminishing marginal returns to erosion control measures. Since fruit trees such as avocado and macadamia can provide erosion control as good as, or better than, wood trees, the presence of fruit trees may weaken one incentive to plant wood trees. On the other hand, fruit trees may merely be a proxy for the degree of erosion to which a particular parcel of land is susceptible; since fruit trees cannot adequately substitute for the fuel production of wood trees, those farmers with more steeply sloping parcels who face a great degree of potential soil loss may plant more of both fruit and wood trees.[7]

Finally, we expect land area to have a positive effect on tree growing, holding labor endowments constant, because more land area will raise the opportunity cost of agricultural labor. Greater land area will of course also increase the absolute number of trees if the number of trees per unit land area is unchanged. This is not to exclude the possibility, however, that trees per acre will decline as land area increases because of diminishing marginal returns to trees for fuelwood, erosion control, and as a form of savings.

In summary, our expectation is that tree growing among smallholders in the Kenyan study site is positively correlated with land area and income, negatively correlated with labor, and ambiguously related to the number of fruit trees.

For the Tanzanian village, expectations are less clear, in part because of a lack of similar information. But in this site, many farmers continue to gather wood illegally from the Kilimanjaro

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[7] To clarify this, consider the following simple example: Suppose that all farmers with flat land grow 2 wood trees and 1 fruit tree per acre; on slopes of 15 degrees, farmers grow 4 wood trees and 6 fruit trees per acre; on slopes of 30 degrees, farmers grow 6 wood trees and 30 fruit trees per acre. In this case, there will be a positive relationship between wood trees and fruit trees in a random sample of farms, even though the ratio of fruit trees to wood trees increases with the slope of the land. This implies that the relationship between fruit and wood trees is ambiguous.

forest reserve, although fewer than in the 1980's -- the government increased patrols along the forest boundary around 1989. In addition, the deep riverine valleys near the village are public land, unlike in the Kenyan site, and many households gather wood from these lands. The result is a much lower price of wood in the Tanzanian site; tree-growing in consequence does not assume the same importance to farmers as it does in Kenya. Fewer Tanzanian farmers have planted trees recently, and fewer are actively engaged in the wood market. Most farmers continue to harvest branches from the large, indigenous trees inherited with their farm fields. In consequence, we do not expect as tight a relationship between the independent variables and tree-growing as in Kenya, although we expect the same direction of impact for these variables.

Econometric model of household behavior

In order to estimate the relationship between tree growing and household characteristics, it is necessary to counter two econometric difficulties. The first is censoring. Since no household can grow fewer than zero trees, our data are censored at the lower end. Furthermore, our data are also censored at the upper end of the range because of coding in the survey. Farmers with large woodlots had difficulty estimating the large number of trees owned, and frequently answered simply that they had many trees. For this reason, enumerators were instructed to ask such farmers if they had more than fifty trees, and to code all responses of more than fifty the same. In our data, then, we cannot distinguish among households with 50 or more trees. Almost 40 percent of the Kenyan sample and 25 percent of the Tanzanian sample reports having zero or 50 or more trees, implying that censoring could be a major problem.

The second difficulty concerns functional form. There is no obviously correct functional form to use for relating the number of trees grown to the independent variables. A technique that allows flexibility in terms of functional form would be desirable.

An ordered multinomial logit model addresses both of these problems. Ordered logit analysis is a standard method used to investigate categorical, yet hierarchical data, such as bond ratings (Greene 1993). (See Appendix for the mathematical formulation of the ordered logit model.) Ordered logit is set up to deal with the censoring issue. Furthermore, ordered logit does not assume that the difference between categories one and two is related in any systematic way to the difference between categories two and three. The resulting functional form is thus quite flexible. The price paid for a flexible functional form is the loss of information contained in the cardinality of the number of trees. Given our censoring problem and our skepticism about any particular choice of functional form, however, the price is well worth paying.

The households were grouped into 10 categories based on the number of wood trees owned, as shown in Table 9.3 at the end of the chapter. Categories are centered on multiples of 5 since many respondents were rounding in their responses.

The independent variables are calculated from farmer responses. Land in the Kenyan village was surveyed at the time of granting title deeds, so unlike many rural areas most of these farmers know the size of their holding. Estimation errors for land size are almost certainly larger in the Tanzanian village. For the labor variable, we use the total household labor available for agricultural work. This variable is calculated by adjusting household size for the age composition of the household and the reported primary occupation of each member.[8]

For the income variable, we use expenditures per capita per annum, including the value of food consumed and produced on the farm.[9] As discussed in Chapter 4 and in common with most developing country surveys, we deem the expenditure data to be a better proxy for income than reported income data (Visaria 1980). In addition, expenditures are likely to be closer to an estimate of permanent income, fluctuating much less than income from year to year. This

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[8] One unit of agricultural labor is defined as an adult man or woman who is aged 14-60, is not in school, and has reported her primary occupation to be farming.   Fractional values are assigned to children and the elderly, those engaged in extra-household employment, and those in school.

[9] The inclusion of expenditure on fuelwood in the expenditure variable could lead to some simultaneity between total expenditures and tree growing. Given that cash expenditures on fuelwood constitute less than two percent of total expenditures, the degree of simultaneity should be slight. Furthermore, the direction of bias would be negative if growing more wood trees is negatively correlated with fuelwood expenditure. Thus, to the extent that any bias exists, it would make our hypothesis that income has a positive impact on tree growing harder to establish.

variable enters the equation in logs since it is more plausible that a percentage rather than an absolute change in income has a constant impact on tree growing.[10]

Model Results

Table 9.2 presents results from the ordered logit model, along with "elasticities." The elasticities are calculated for the expected value of the number of trees per household, for a farm with independent variables at their means.[11] These calculations allow us to explore the relative size of the impact of the independent variables on the expected number of trees.

The expenditure variable is important in size (as measured by its elasticity) but lacks statistical significance in both equations. The land variable is similarly important in size, and is significant in both equations. The fruit trees coefficient is important, positive, and significant for Kenya, while insignificant in Tanzania; as mentioned above, this the positive coefficient could be a proxy for the amount of highly-sloped land on the parcel. The labor coefficient is unexpectedly large and positive in both equations, although it is not significantly different from zero for Tanzania.

The overall fit of the model is quite good for both equations, although better for Kenya. The relatively poorer fit of the Tanzanian regression is in accord with our expectations. With lower fuelwood prices because of readily-accessible public lands from which to gather wood, wood-growing is much less profitable, and many farmers simply grow the same number of trees they inherited with the land. It is interesting to note, however, that although the relationships between the dependent and independent variables are not as tight, the average relationships as indicated by the elasticities are rather similar in the two villages.

As expected, households with greater land area are likely to have more trees. The elasticity of the expected value of the number of trees grown with respect to land, however, is less

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[10] Our functional form assumes that a 2000 Ksh increase in expenditure per capita for a household spending 20,000 Ksh per capita has the same impact on the latent variable in the ordered logit as a 200 Ksh increase in expenditure per capita for a household spending 2,000 Ksh per capita. A linear functional form would assume that the former has 10 times the impact of the latter; we view this as implausible.

[11] We calculate the elasticities by first calculating the expected number of trees grown by a household with all independent variables at their means. The elasticity, then, is the percent increase in this expected value that results from increasing an independent variable by one percent.

than one, indicating that households with less land grow more trees per acre holding the other independent variables constant. Dewees (1991) makes an even stronger claim, arguing that households with very small parcels will grow an absolutely greater number of trees than households with larger holdings because it is uneconomic for them to rely upon agricultural production as the sole source of income. As labor is diverted to non-farm employment on smaller farms, trees become a good land use option because they require relatively less labor. Our results are in stark contrast to this hypothesis. A household with less land is likely to grow fewer trees,

TABLE 9.2: Ordered Logit of the determinants of tree growing

	Coefficients		Elasticities	
VARIABLE	Kenya	Tanzania	Kenya	Tanzania
Constant	-3.82	-4.10		
Land	0.373***	0.117**	0.36	0.36
	(2.71)	(2.42)		
Labor	0.371***	0.302*	0.40	0.46
	(2.64)	(1.84)		
Ln expenditure per capita	0.557	0.493	0.24	0.30
	(1.42)	(1.15)		
Fruit trees	0.0396**	0.0142	0.19	0.12
	(2.30)	(1.22)		
n	110	115		
log likelihood	-205.0	-203.9		
restricted log-l	-221.7	-214.0		
c2	33.3	20.1		
Sig. level	1.05E-05	4.69E-04		

Notes: t-statistics are in parentheses. One, two, and three asterisks indicate significance at the 10%, 5%, and 1% level, respectively. Elasticities are for the expected value of the number of trees, taken at the mean holding labor availability constant; if some of that labor is then involved in non-farm work, the household is likely to grow even fewer trees.

Contrary to our expectations, households with more labor available for agriculture are likely to have more wood trees. This result is robust across alternative specifications (Patel 1993). One possible explanation is that larger households have larger fuelwood requirements, and therefore grow more trees in a poorly-functioning market for fuelwood. We tested this hypothesis by substituting total household caloric demand, estimated by adjusting household size for age composition and gender, for the agricultural labor variable in the ordered logit regression.[12] The coefficient of this calorie demand variable is smaller in size than the labor availability variable and insignificantly different from zero. Therefore, this unexpected result is a labor effect, and not a demand for fuelwood effect.

Another possible explanation is that, while trees in pure stand use little labor, interplanting trees with other crops requires more labor than pure stands of crops in order to compensate for nutrients, water, and sunshine absorbed by the trees. Conceivably this hypothesis could be tested by distinguishing those trees planted in lots from those planted in fields. Our data, however, do not allow us to make this distinction.

The model also suggests that households with more income per capita may be likely to grow more trees. Although the results lack statistical significance at the usual confidence levels, the elasticity is substantial in size, particularly in Kenya, where a one standard deviation increase in this independent variable increases the expected number of trees planted for a representative farm by 12 percent. This result contrasts with the argument of Dewees (1991), who contends higher income will enable farmers to abandon trees for supposedly more profitable crops such as maize or coffee. Our econometric results are thus consistent with the finding that trees are competitive with maize and relatively more profitable for households with lower discount rates and higher opportunity costs of labor. Thus, households with higher incomes, which are likely to have relatively low personal discount rates, appear to be more likely to grow wood trees. It follows that

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[12] Total household caloric demand is calculated according to age group and gender values as reported by Latham (1965).

rising average per capita income in the area may give rise to more tree growing; furthermore, policies that lower discount rates directly by improving access to long-term credit may have similar effects.[13]

Land subdivision, tree planting, and the environmental Kuznets' curve

Although we find that households with large land holdings are likely to have more trees, the elasticity of tree-growing with respect to land size is less than one. This elasticity implies that if the other variables are held constant, the number of trees per acre will increase as there is land subdivision, the predominant form of land transaction in the community (Pinckney and Kimuyu 1994 and Chapter 10). Thus, there may be no downward spiral of environmental degradation due to population pressure. This is consistent with the observation that the market signals that would accompany increasingly scarce fuelwood appear to be present; wood prices have risen dramatically in the last few years.

Other variables will not be constant, however, as land is subdivided. In our sample, there are negative relationships between land and per capita income, land and fruit trees, and land and labor. Once these relationships are considered, it is not at all clear that subdivision will lead to a greater number of trees planted per acre.

In order to clarify this point, we simulate the effects of population increases and resulting land subdivision on tree-growing using the ordered logit model for Kenya. The mean values for land area, labor availability, expenditures per capita, and fruit trees are taken to describe the average household. Average land area per household is then doubled, halved, and quartered to simulate a stepwise subdivision of an original parcel of 4.5 acres into eight parcels of equal size. In the first simulation, fruit trees, income, and labor are assumed to decrease with land in the

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[13] Again, this contrasts with Dewees (1991). He concludes that better functioning credit markets may result in a reduction in tree growing activity. We expect improvements in credit markets to increase tree-growing for two reasons. First, the direct effect of lowering the cost of tree-growing through lowering the cost of credit is likely to dominate any secondary effects of parcel aggregation on tree-growing. Second, improving long-term credit is unlikely to lead to parcel aggregation in this community, for many of the same reasons that granting title deeds did not lead to parcel aggregation. See Pinckney and Kimuyu (1994).

same way that they decrease in the sample.[14] In the second simulation, we bias our results against the conclusion that the density of trees increases as land size decreases by assuming that these three independent variables decrease with land size at double the actual rate in the sample.[15] Values of the independent variables used in the simulations are presented in the appendix in Table 9.4. The ordered logit results allow the calculation of the probability that this average household will be in one of the ten categories of tree-growing. These probabilities are then multiplied by the mean number of trees in each category to produce the expected number of trees per household.[16]

The results of the first simulation, the more likely of the two, are presented in the two panels of Figure 9.1. As parcel size decreases from 4.5 acres to 0.56 acres, the expected number of trees per household decreases from 50 to 19, but the expected number of trees per acre increases from 11.1, when farm size is double the present value, to 13.4, 20.0, and 34.3 as farm size is, respectively, its present value, half, and one-quarter its present value. The probability of a household having 50 or more trees decreases dramatically from 60 to 17 percent over this range of parcel sizes, while the probability of having no trees increases from 1 to 8 percent, but the increasing number of farms more than offsets these decreases.

The second simulation, in which results are biased against finding an increase in trees per acre, is in a sense even more dramatic. As parcel size declines from 4.5 acres to 0.56, the

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[14] For these simulations, we use coefficients of simple regressions with fruit trees, income per capita, and labor as dependent variables and land as the independent variable.

[15] According to theory, trees planted should increase as labor available decreases, holding other variables constant. In that case, doubling the rate of decrease of labor as land decreases would improve the likelihood of the household planting more trees. But since the ordered logit model estimates a positive coefficient for labor, this assumption does indeed bias the result away from finding that households with less land will plant more trees.

[16] Means of categories are provided in the appendix in Table A1. In most categories, the assumed mean is the multiple of 5 around which the category is centered. The most difficult category is the highest, those households with 50 or more trees. Here, taking a mean was not possible; furthermore, decreasing the size of the farm is likely to decrease the mean of this category since the largest woodlots would have to decrease in size. We have made what we think is an extreme assumption: the mean number of trees in this group starts at 70 in simulation 1 and 100 in simulation 2 when farm size is double its present mean, and then moves toward 50 in the same proportion that mean farm size moves toward zero, thus ending at 56.25 and 52.5 in simulations 1 and 2. Again, we believe we are biasing our results against the possibility of finding that the number of wood trees goes up as farm size decreases.

Figure 9.1A. Simulation 1: Effects of land subdivision on trees per household

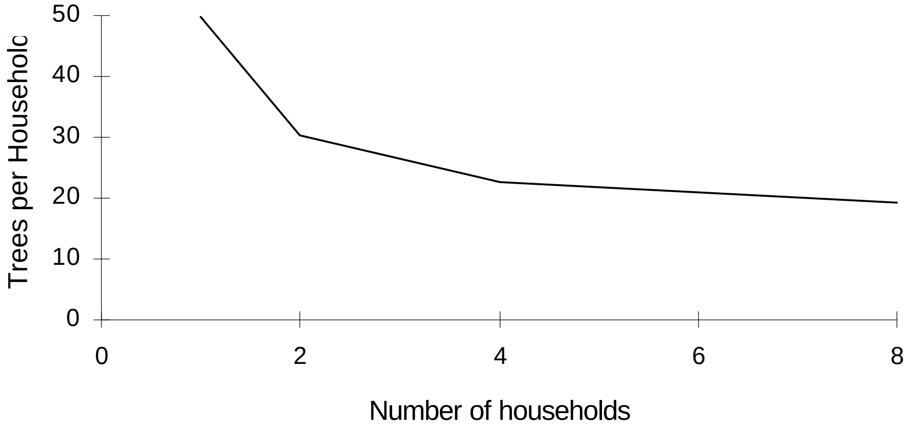
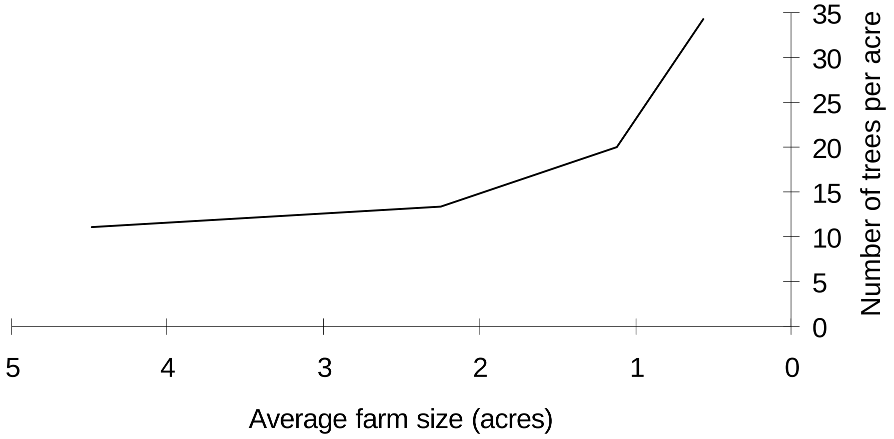


Figure 9.1B. Simulation 1: Effects of land subdivision on trees per acre



number of trees per household falls from 73 to 18. The fall, however, is at a decreasing rate, so that we still find a substantial increase in the expected number of trees per acre -- from 16.3 to 31.7 -- even though our results are biased against such a finding.

Clearly, the effects of rising population density extend beyond land subdivision, and will affect labor use, migration, food prices, and household characteristics, all of which may affect fuel wood markets and tree planting. Nevertheless, here we have made several extreme assumptions about the effect of subdivision on expenditures, labor use, and fruit trees that would tend to bias our results against the findings in Figure 1. Furthermore, simulations using parameters from the Tanzanian equation yield similar results. Thus, the findings appear robust despite the noted qualifications.

We expect to see an increase in total tree cover as average farm size decreases even to one-fourth of its present level. Although the causal relationship underlying this result may be somewhat different, the pattern is consistent with the Boserup (1965) hypothesis that population density gives rise to high payoff investments (innovation in her example). It is also analogous to the evidence of an "environmental Kuznets curve" where environmental degradation is shown to worsen, then improve, as per capita incomes improve.

Conclusions and policy implications

Evidence of a market "gap" and persistent woodfuel crisis in African countries like Kenya is not supported by this study. The planting of wood trees is found to be competitive with other production activities, and farmers appear responsive to the incentives to plant trees. The behavioral model presented here indicates that households with larger landholdings and higher income are more likely to plant trees. To our surprise, households in our sample that have greater farm labor resources are also likely to have larger numbers of wood trees.

Moreover, differences among households in tree planting activity may reflect differences in factor costs given different factor endowments and poorly functioning factor markets. If farmers are too poor to be able to forgo current production for the future on-farm environmental benefits that trees provide, their condition will only worsen as their land is degraded.

Based on our cross-sectional analysis, however, rising population density and land subdivision does not necessarily imply continued loss of tree cover and further land degradation. Indeed, our simulations based on a representative household suggest that further land subdivision may actually lead to rising tree cover. This result bears some resemblance to the well-known

Boserup hypothesis about agricultural intensification, and it has strong similarities with recent cross-country evidence of an "environmental Kuznets curve," evidence which runs contrary to the hypothesis of a downward spiral of fuelwood gaps and environmental degradation. Our conclusion that rising population density and land subdivision may become positively correlated with rising tree density at some point reaffirms the potential difficulty of linear extrapolation from historical trends and the failure to recognize corrective feedbacks in dynamic systems.

Despite this reassuring analysis, there still exist at least three potential market failures that would give rise to sub-optimal tree stocks in East Africa. First, the external economies from trees include a critical role in watershed management, especially in fertile highland regions. These include reducing widespread soil erosion, moderating runoff by increasing water infiltration and soil storage capacity, and protecting biodiversity. Loss of these benefits can be large. Indeed, in another part of Kenya, the exploitation by clearing and cultivation of such watershed lands has led to ethnic tensions and violence (Weekly Review Oct. 29, 1993). Failing to consider these non-market benefits will result in an undersupply of tree stocks and, hence, fuel wood as well.

Second, farmers cannot effectively counter large scale erosion individually. If only the farms in vertical strips down a steep slope decide to plant trees, there will still be substantial erosion. The arrangement of trees, not just their number, has an important bearing on the external economies of erosion control in the aggregate. Thus, there may be synergy to individual farmers' decisions--the benefits society derives may be contingent upon many individuals taking coordinated action with the arrangement of trees. The many individuals, however, may not have sufficient incentives to maintain cooperation.

Third, while the number and arrangement of trees is critical, the composition of tree species is also important. Evidence of an "environmental Kuznets curve" may be reassuring in terms of numbers of trees. But to the extent that the path implies a loss of diversity, there is reason for concern. In our study area, indigenous species have been replaced over the years with exotics. Currently only two or three species are regularly planted -- primarily eucalyptus and *G. robusta*. These high concentrations of exotic species increase the likelihood of disease or pest infestations that can have catastrophic results, such as the Cyprus blight that has plagued both Kenyan and Tanzanian highlands in recent years (Ngugi and Bradley 1986). Species composition can also change even when total tree cover is in decline, because of selective cutting of unwanted species (Castro 1991).

As the average land holding in Kenya decreases, farmers must try to produce fuelwood on their increasingly limited land area. Increasing density of planted trees--and the shift toward monoculture of fast growing exotics--is exacerbating the social costs of these practices since high tree density is likely to raise the risk of infestation. Anecdotal evidence from Tanzania suggests a similar trend in species change is taking place: farmers in the vicinity of a national forest who started growing trees have all chosen eucalyptus or *G. robusta*.

Evidence of well-developed fuel wood markets and of corrective feedbacks that may be at work to reverse current trends of declining tree cover should serve to focus government's efforts on averting market failure, rather than to obviate the need for government intervention. Our results indicate that tree growing is likely to increase with increased population density. Government needs to focus its attention not so much on increasing the total number of trees, but on alleviating credit market imperfections, facilitating optimal spatial distribution of trees, and encouraging diversity.

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APPENDIX: THE ORDERED LOGIT MODEL

Assume that an unobserved, continuous variable z is a linear function of four independent variables:

$$z = b_0 + b_1X_1 + b_2X_2 + b_3\ln X_3 + b_4X_4 + \varepsilon \quad [1]$$

where X_1 = land, X_2 = labor, X_3 = expenditure per capita, X_4 = fruit trees, and ε is a random error term distributed logistically. Furthermore, assume that z is related to y, categories of the number of wood trees growing on a farm, in the following manner:

$$y = 0 \text{ if } z < m_0 \quad [2]$$

$$y = i \text{ if } m_{i-1} < z < m_i \text{ for } 1 < i < J \quad [3]$$

$$y = J \text{ if } m_{J-1} < z \quad [4]$$

where J+1 is the number of different categories of wood trees considered. Without loss of generality, we can rescale z so that $m_0 = 0$.

In the estimation reported in Table 9.2 above, we divide the number of trees into 10 categories. This implies that we need to estimate 8 parameters m_j (excluding m_0). Estimation is accomplished via maximum likelihood techniques. The number of trees in each group is reported in Table 9.3.

Once these parameters are estimated, the probability that a household with a particular predicted value of z, z_p, has trees in each of categories 1 to 8 is:

$$f(m_j - z_p) - f(m_{j-1} - z_p)$$

For categories 0 and 9, the probabilities are $f(- z_p)$ and $1-f(m_{17} - z_p)$, respectively. In all these cases, $f(x) = e^x / (1 + e^x)$. In most cases, these probabilities are then multiplied by the number of trees per farm in each category in order to calculate the expected value of the number of trees planted for the simulations reported in Figures 9.1 and 9.2. The only exception to this is for the highest category, 50 or more trees. For this category, the mean number of trees might decrease substantially as mean farm size decreases, since the largest woodlots would have to decrease in size. To account for this, and to bias our results against finding that the number of wood trees per acre increases as farm size decreases, we assume that the mean number of trees in this category moves toward 50 in the same proportion that mean farm size moves toward zero. Assumptions are reported in Table 9.4.

Table 9.3: Categories of Trees for Ordered Logit Analysis

Category Number	Number Of Trees	Frequency		Assumed Mean For Simulations	Tanzania		Kenya	
		Tanzania	Kenya		Estimated Value of m	Standard Error of m	Estimated Value of m	Standard Error of m
0	0	8	7	0	0	0	0	
1	1,2	9	6	1.5	0.87	0.29	0.74	0.31
2	3-7	42	9	5	2.86	0.40	1.46	0.39
3	8-12	16	17	10	3.53	0.41	2.37	0.42
4	13-17	9	9	15	3.97	0.43	2.77	0.43
5	18-22	4	14	20	4.18	0.43	3.39	0.45
6	23-27	2	3	25	4.30	0.44	3.52	0.46
7	28-32	3	6	30	4.48	0.44	3.83	0.47
8	33-49	1	3	40	4.54	0.44	3.99	0.48
9	>=50	21	36	See Table 9.4				

Table 9.4: Descriptive Statistics and Simulation Values for Kenya

			Values in Simulation 1				Values in Simulation 2			
	Mean	s.d.	1	2	3	4	1	2	3	4
Number of Wood Trees/HH	28.9	23.4	49.7	30.2	22.5	19.3	73.1	35.0	22.5	17.8
Log of Expenditures/Capita	8.73	0.52	8.83	8.73	8.68	8.66	8.92	8.73	8.63	8.58
Number of Fruit Trees	10.94	9.62	13.86	10.94	9.48	8.75	16.77	10.94	8.02	6.56
Land Area (acres)	2.25	2.66	4.50	2.25	1.13	0.56	4.50	2.25	1.13	0.56
Labor Available for Agriculture	2.54	1.44	2.86	2.54	2.39	2.31	3.17	2.54	2.23	2.07
Mean of Highest Category			70	60	55	52.5	100	75	62.5	56.25

Notes: For the number of wood trees, the mean and standard deviation are calculated setting all households in the highest category to 60.

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