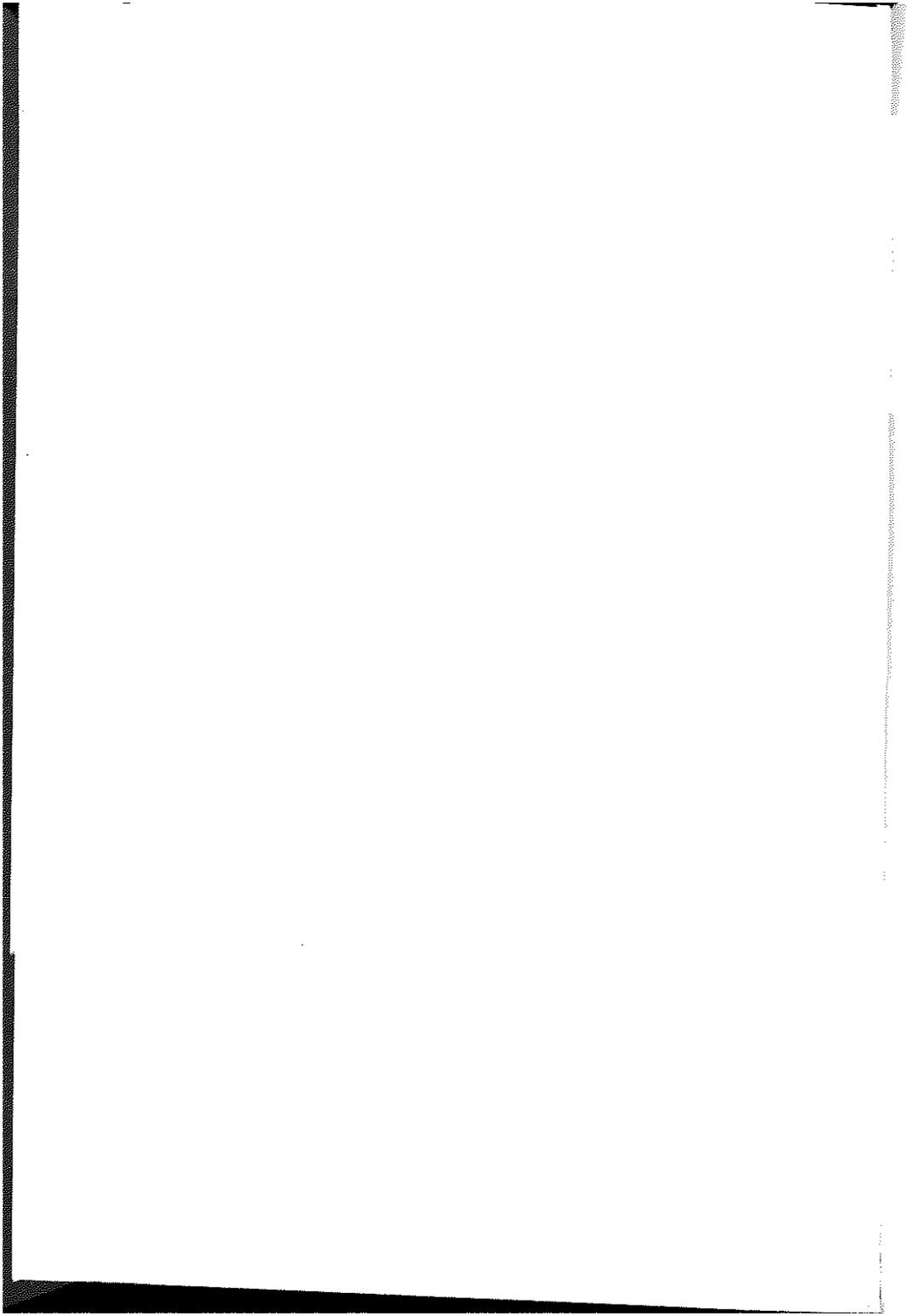


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**Perspectives on Poverty and Resource  
Degradation**

by  
Wilfred Nyangena

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Perspectives on Poverty and Resource  
Degradation

By Wilfred Nyangena

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### 1. Introduction

Concerns about poverty are at the top of the development agenda in many developing countries. Nowhere in the world, is the environmental resource base more intensively utilized than in Sub-Saharan Africa (SSA). Up to 65 percent of the population in developing countries is agrarian and pastoral (Dasgupta and Mäler 1995). In 1998 alone, the share of labour force in the agricultural sector contributed 30 percent of GDP. This is in stark contrast to the industrial economies where agriculture contributed only 2 percent of GDP and employed only 6 percent of the labour force. A glaring fact is that, for a long time to come, Sub-Saharan Africa (SSA) will still be reliant on agriculture. This is worrisome because the very resource base that provides livelihood is under threat of exhaustion from excessive use.

An emerging issue in the poverty debate is how to explain the notably close links between poverty and resource degradation<sup>1</sup>. For instance is it forest degradation that causes low agricultural productivity, leading to declining labour and capital productivity followed by less marketable output and consequently poverty? The debate goes even further to focus on off-farm costs, including downstream flooding, damage to Hydro Electric Power (HEP) plants, irrigation systems and reduced productivity of coastal ecosystems.

Among the emerging explanations attempting to address the phenomenon, is the argument that poverty and resource degradation occur in a downward spiral, causing destitution (Brundtland Report-WCED 1987). The alternative, and equally prominent, school contends that it is the decline in resource base quality, associated with institutional factors, that causes poverty. They caution against the simplistic linear causality advocated by the other school. Their contention is that a complex and intricate

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<sup>1</sup> The concept of resource degradation employed in this paper is the decline of renewable resource stocks.

web of forces, acting and reinforcing each other, causes resource degradation and poverty (Leach and Mearns, 1995).

We adopt an approach that emphasizes a specific resource and analyzes the human impacts of such utilization (UNEP 1995, OECD 1998). We extend the analysis to identify the main agents, their economic motivation, and the socio-economic and ecological impacts of their actions. This approach allows more insight and identification of the complex web of factors in the poverty and resource degradation nexus. That is one of the contributions that this paper will make with reference to forest resource.

The micro economic causes and effects of resource degradation have been studied in a number of settings<sup>2</sup>. An article by Barret (1994) analyses the impact of pricing and soil conservation efforts. While several studies have provided useful insights on resource degradation, the links to poverty are yet to be addressed. The symbiotic relationship between soil quality and vegetative cover is inseparable from the economic malaise of SSA. This lifeline link between ecological status and income streams, has also been largely ignored in many studies.

The purpose of this paper is to develop a household model that will predict changes in well being, in response to changes in stocks of forest or natural capital. We borrow from economic theory in analysing the optimal patterns of use. This is important because any efforts to combat poverty and resource degradation must target those variables, through incentives that can alter individual behaviour. This paper aims to make a contribution to this end, as it simultaneously derives comparative static theoretical results for future empirical work.

The rest of the paper is structured as follows: in the next section we review the literature on poverty and deforestation. Thereafter,

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<sup>2</sup> See (Dasgupta and Heal (1979); Barret (1991); Baland and Platteau (1996) for instance.

we explain the theoretical model used to derive the analytical results, and finally we give our conclusions.

## 2. Previous Studies on Poverty and Resource Degradation Nexus

We postulate a number of causality relationships which have been identified in the literature, but for which quantitative empirical analysis is still lacking. We, thus, highlight five central relationships. We begin with the popular notion of poverty-environment degradation, which states that it is poverty that causes environmental degradation. The poor have few alternatives other than exploiting the resource base, which is their productive asset as well as consumption basket. Consequently, poverty induces the poor to overuse the resource base. This is what we call Hypothesis One (or H1) summarised as:

H1: Poverty  $\rightarrow$  Environmental Degradation.

An emerging argument is that it is poor governance, vested interests and bureaucracy in many developing countries that causes environmental degradation. The study by Boyce (1994) argues that the combination of greed, power and wealth causes environmental degradation. Dasgupta (1993) also alludes to this issue when he invokes the link between civil and political liberties with well being. When political and civil liberties are extremely rare, it is a reflection of deprivation to resources. It is those in power and with authority that take advantage of the lack of civil state to gain control of resources. The way this elite class 'grabs' public resources is astounding as documented by Bauer (1981), Hancock (1989), Repetto (1988) and Binswanger (1989). The misdeeds include outright theft of official aid, subsidized credit facilities, misuse of official position to impose producer price controls in agriculture, and imposition of trade restrictions. Such controls on producer prices and trade create rents, which often end up in the hands of those who foster such controls and restrictions. All these have painful implications on distribution

and poverty and, in a way, erode the resource base of a country. This is what we call Hypothesis Two (or H2) summarised as:  
H2: Greed, Power and Wealth → Environmental Degradation

The third causality relationship identified in the literature is market failure. Very broadly, some authors classify it as the policy variable. There are certain government policies that encourage environmental degradation.<sup>3</sup> Among the issues highlighted include the potential detrimental effects of government policies towards environmental degradation. Policy distortions, emanating from government-supported minimum prices, and input subsidies, are likely to increase deforestation, overstocking and soil exhaustion among others. All these send the wrong signals to the actors concerned. This is what we call Hypothesis Three (or H3) summarised as:

H3: Market failures → Environmental Degradation

Closely related to H3, above, is the institutional failure category. Until recently, it has been assumed that, environmental problems are largely associated with the failure of market institutions (Mäler, 1974). Recently, a number of authors have asserted that inappropriate government policies are to blame for environmental degradation. Unfortunately, most of them brand both mechanisms, generally, as institutional failures. However, as has been pointed out by Duraiapah (1998), there is need for distinction, as they are different particularly from a policy perspective. He cites the example of a policy initiative to address incorrect price signals (market failure) as being quite different from the need to establish and enforce well-defined rights

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<sup>3</sup> See Binswanger, H (1991) Brazilian Policies that Encourage Deforestation in the Amazon. *World Development*, Vol. 19 821-829.  
Peterson, A and Munasinghe, M (1995) "Natural Resource Management and Economy wide Policies in Costa Rica: A CGE Modelling Approach" *The World Bank Economic Review*, vol. 1

(institutional failure). It is on that strength that we have split the two in this analysis.

The importance of security of tenure in the conservation of a resource, and the prevention of its degradation, need not be emphasised. It is argued that the answer to resource conservation lies in formal and individual title to land. This is borne out of the erroneous observation that communal tenure institutions are associated with open access problems. This is what we call Hypothesis Four (or H4) summarised as:

H4: Institutional Failures → Environmental Degradation.

The other end of the continuum is a relationship that could emerge from any of the above-cited relationships H1, H2, H3, and H4. For example, our fifth hypothesis, summarised below as H5, states that environmental degradation leads to poverty.

H5: Environmental Degradation → Poverty

If H1 alone is observed, then poverty-induced environmental degradation thesis holds, and it would be prudent to tackle environmental protection through poverty mitigating policies. On the other hand, if environmental degradation is caused by H2, then the policies outlined in H1 cannot be viable and could lead to further degradation, as shown by Binswanger (1989). The study demonstrates how, in Brazil, the exemption from taxation of virtually all-agricultural incomes provided incentives for the acquisition of forestlands by the higher income groups and for deforesting them. However, policy prescription for H2 is difficult because of the entrenched interests, and greed, on the part of the wealthy. The first attempt would be the adoption of policies, which internalize environmental externalities. This, again, is quite difficult because of the vested interests. In the long term it is the move towards democratization, and the resultant concentration of political and civil rights, that would ameliorate the problem. A

second best strategy would be pressure at the international market, where most of these commodities are sold. In this case, stricter adherence to a standardized polluter-pays principle would help.

In the case of H3 being responsible for degradation, the answer is clear-cut. Remove, or correct, all the market failures. This, like H2 above, may be difficult to implement, if there are vested interests on the part of the policy makers. The other difficulty lies in identifying the market distortions themselves. With regard to H4, (institutional failures) the answer is quite similar: correct the institutional failure. The difficulties are also along the lines outlined in H3. Lastly, in the event of H5 being the cause of environmental degradation, then two situations could emerge. The first is that, H1, H2, H3, and H4 or, various combinations of all of them cause H5. The second is that, the presence of H5 can set into play a H1 type of link.

A number of other interesting situations could also emerge from various combinations outlined above. Beginning with an H1-H5 linkage, it is possible that that H1 causes H4 and the causal link ends there. However, there is the possibility that the poverty caused by H5 causes more degradation, as has been argued by most commentators on the issue. This is the self-reinforcing outcome that sets a downward spiral as illustrated by Durning (1989). In this situation, the policy measures taken should concentrate on eliminating the problem, at source, and this is what the advocates of the Bruntland and the World Bank have in mind.

If, on the other hand, the situation is one of H2 and H5, then there may be open conflict, even among the resource users. Once the welfare of the powerful and wealthy is tampered with by another group, then perhaps internalisation of externalities will begin assuming the existence of a strong civil society. In the absence of such a society, then anarchy will set in, as has been demonstrated by Dixon (1996). The interesting issue here is the

role of environmental scarcity in promoting resource-based conflict. However, this is beyond the scope of this paper and is left out as a potential issue for further research.

Lastly, supposing that there is a situation where all the conditions H1, H2, H3 and H4 are present, simultaneously, and combined they strengthen H5. The solution to this is extremely difficult and not as straight as the others outlined above. For one, we have market and institutional failures, power and wealth, and poverty, all working on the environment. Policy prescription, at this level, may be a trial-and-error exercise. For example, policies targeted at poverty will have limited impact, if the main driving forces of environmental degradation (i.e. market and institutional failures) power and wealth are still present. Perhaps, this is one reason why many efforts targeted at poverty-environmental degradation reduction have failed.

### Forestry

The focus of this paper is not deforestation per se, because deforestation may be a necessary condition for economic development, but rather, we focus on the rate at which forests are removed. The example is given of Sweden that utilized her forest resources during the early development stages. What is important, however, is that the rate of use should not exceed some threshold level which, in turn, would set in motion negative feedbacks. These negative feedbacks have implications on the ecological and economic systems on which humanity, particularly in developing countries, depend.

#### *Activities that mainly contribute to deforestation*

In the literature on deforestation, three reasons are cited for the destruction of forests in developing countries: (i) the gathering of fuelwood, (ii) the conversion of forest and woodland to pasture and cropland, and (iii) commercial logging. In all these activities, population pressure is cited as an underlying cause. It is often argued that, population growth increases the demand for fuelwood and timber. Population growth also, by increasing the

demand for arable land, encourages the conversion of forests to agriculture.

Large proportions of people (80 per cent) in developing countries use fuelwood as their main source of energy. This has been seen as the contributory factor to deforestation. In this regard, Southgate and Pierce (1988) cite small-scale farmers as the main agent responsible for deforestation. Their study estimates that, of the 17.6 to 19.2 million hectares of forest cleared in the Brazilian Amazon, 2 million could be attributed to fuelwood gathering and close to 10 million hectares to small-scale farmers alone. Southgate (1988) adds another interesting dimension to the debate by arguing that population growth was the prime contributor to the unsustainable deforestation, especially in tropical Africa and the Amazon basin. The study also highlights the critical role that livestock and agricultural subsidies played in providing incentives for deforestation to occur. In a similar fashion, FAO (1993) concluded that agricultural expansion, driven by population pressure, was the primary force behind tropical deforestation.

Jainvry (1993), singled out both government policies (need for foreign exchange, the need to resettle the landless etc.) and population pressure as providing the incentives for people to move into these areas and convert large tracts of land into agricultural land permanently. An econometric study by Cropper and Griffiths (1994) looked at the effect of population pressures on deforestation for developing countries covering Africa, Latin America and Asia. The relevant result is that an increase in rural population density of 100 persons per 1000 hectares raises the rate of deforestation by 0.33 per cent points in Africa. In its interpretation of the results, the study argues for the establishment of property rights. Such rights are currently not often defined and, even where they exist, they are rarely enforced since the private cost of deforestation is zero. However, none of these studies makes an explicit link between population growth and poverty.

There are other proponents that point to logging as the principal contributor to unsustainable deforestation. The study by Cropper and Griffiths (1994) endorses the hypothesis that logging causes deforestation since there is a significant correlation between the price of wood and the rate of deforestation in Asia and Latin America. Repetto (1990) attributes commercial logging as the number one agent for deforestation in tropical forests. The same sentiments are echoed by Somanathan (1991), who cites commercial interests, driven by government policies, as the primary incentive for deforestation in the Himalayas. Other studies have pointed out that agricultural and livestock rearing is the primary force behind deforestation, and that logging has just been the catalyst. They further attribute deforestation to the key role played by the creation of infrastructure for agriculture and livestock rearing. Goodland (1991) cites cattle ranching and unplanned settlement as the main causes of deforestation in Brazil. It is the logging trails that initially opened up these large tracts of forestland to massive deforestation.

Another interesting explanation for deforestation is provided by Davidson (1993) who argues that, many countries, in a bid to reduce their foreign debt arrears, implemented policies which first, encouraged the felling of trees and later, the cultivation of crops meant for the export market. The author attributes close to 50 per cent of all deforestation in the tropics to this practice. Jaganathan (1989) re-emphasizes the important role played by market failure, as a contributory factor to deforestation in Indonesia. The same pattern of logging, followed by conversion of the former forestland into estates and gardens is found. The study, however, did not find much correlation between poverty and deforestation, and the only time that peasants were involved in unsustainable activity was when they tended unproductive land, abandoned by previous landlords. Lutz and Daly (1990), who explicitly mention that squatters' contribution to deforestation was minimal, strongly support this view. They argue that squatters and the poor do not have the resources needed for deforestation. The authors argue that those involved in deforestation did so with the

intention of selling the land to ranch owners later. They singled out banana companies, cattle ranchers and logging companies, as the prime actors in deforestation in Costa Rica.

Table 1 summarises the literature reviewed thus far.

*Table 1: Summary of Findings of Literature Reviewed*

Enterprise	Agent	Incentive	Motivation	Relationship
Fuelwood collection	Small-holder	Subsistence	Insecure land rights	H1
	Commercial	Profits	Markets	H2, H3 and H4
Logging	Commercial	Profits	Government policies, market	H2, H3 and H4
Agriculture /livestock	Commercial	Profits	Government policies, market	H2, H3 and H4
Pastoralism	Small-holder	Subsistence	Food security	H1

#### *Social and Economic Impacts of Deforestation*

In this section, we look at the impacts of the various activities and agents particularly, the ways in which they impact on the vulnerable in society. There are various social and economic impacts of deforestation identified in the literature. They range from fuelwood deficits, loss of watershed protection to soil erosion.

#### *Fuelwood scarcity*

Fuelwood is the principal source of energy to over 60 per cent of people in the world today. The primary uses today are space heating and cooking. In Kenya alone, over 80 per cent of the population is entirely dependent on fuelwood for cooking. Tolba, *et al.*, (1992) estimated that, in 1980 alone, 1.3 billion people faced

fuelwood shortages and the number was bound to increase to 2.7 billion by the year 2000. The implications of this grave scenario weigh heavily on the poor, on whom the incidence falls. A number of studies, looking at the household time budgets, have recently been undertaken. Filmer and Pritchett (1996), using Integrated Household data from Pakistan, found that, in times of fuelwood scarcity, collection activities consumed a substantial proportion of the household's time, accounting for 6.2 per cent of household expenditure.

A rather bizarre finding from the study is that children, especially those aged 15 years and above, significantly contributed to relieving mothers for other chores by 3.2 hours per child in a week. The implication of this finding is that, fuel wood scarcity could trigger households to have more children, thereby aggravating an already bad situation. The time taken to collect firewood increases as the rate of depletion increases. The longer collecting times imply a larger proportion of time being used for fuel wood collection, and hence, less time left for economic activities. Even though the study is not based on time series data, and hence the difficulty in generalising to relate environmental degradation to fertility, the writing is on the wall: the correlation between large families and poverty needs no explanation.

Dasgupta (1993), in an attempt to understand the forces underlying population growth using economic analysis, found that population growth is linked to poverty, gender inequalities, the communal responsibility of raising children, and, most important in our context, the erosion of the local resource base. Dasgupta and Mäler (1995) also forcefully argue that children augment family income, derived from the exploitation of natural resources, such as fuel wood and water. The cost in this case being the time required to collect these resources. Both studies, not only show the possibility of a positive relationship between rural poverty, fertility, and environmental resource base degradation, but also go on to add that there are also market and institutional failures that contribute to environmental degradation.

There are other studies, however, that point to natural resources scarcity as imposing a limit on the demand for children. Loughran and Pritchett (1999) have recently confirmed a link between environmental scarcity and reduced fertility. Their study, using cross-sectional data from Nepal, sought to investigate the impact of scarcity in firewood and water on demand for children. They found that scarcity of these resources reduced the relative value of children in resource collection, and went on to conclude that, Nepalese households perceive resource scarcity as being responsible for increasing the net cost of children.

#### *Loss of Watershed Protection*

Forests, especially tropical moist forests, serve as important water catchment areas and their loss could have adverse implications on the water cycle. Salati (1985) estimates that 75 per cent of annual rainfall in the Amazon is returned from the forest to the atmosphere and loss of this cover could lead to reduced rainfall in future. Although the precise relationship between forest cover and rainfall is not yet fully understood, Meher-Homji (1986) concludes, from a vegetation rainfall's study, covering 29 stations for over 100 years that, as a rule, the larger the area of deforestation the larger the number of indicators showing a decrease in rainfall. Though the study only looked at localized effects, we anticipate that, if the impacts were to be globalised, the relationship between the hydrologic cycle and forest cover could be significant.

Evidence is also emerging that reduced forest cover in the highlands and mountains, could result in an increased environmental and resource degradation potential, in the lowlands and plains. For example, Somonathan (1991) reports that, the average area in Uttar Pradesh, in India, subject to flooding has increased from 17,000 Km<sup>2</sup> in 1953-65 to 41000 Km<sup>2</sup> in 1976-78, which he attributes to deforestation in the Himalayas. Vohra (1987), who found strong correlation between floods and soil erosion, supports these sentiments.

### Increased Soil Erosion

Jodha (1995) states that, the removal of forest cover reduces nutrient supply of organic matter to the arable lands. Repetto (1994) estimates that 25 million tons of topsoil is lost annually, due to deforestation alone, in India. From an economic perspective, that implies a drop in agricultural productivity and, invariably, incomes. Even if we were able to increase all other variable inputs, like capital and labour, to maintain constant yields, the ultimate result is a drop in agricultural productivity, because of increased production costs, per unit of output, as a result of resource degradation. The problem is aggravated in already marginal areas, where the marginal costs of increasing yields, by far, outweigh the marginal benefits. This is, especially, true of marginal areas of Africa, which also form the communal lands that are worst hit, or most threatened, by environmental and resource degradation.

*Table 2: Summary of the Main Impacts and Groups Affected by Resource Degradation*

Impact	Outcome	Economic group	Relationship
Fuelwood deficit	Drop in labour productivity, Increased fertility, increased household expenditure	Low income	H1 feedback
Watershed loss	Increased flooding potential, disruption of hydrological cycle	All groups but worst hit are the low income	H1 feedback
Soil erosion	Decline in agricultural productivity, reduced incomes, malnutrition	All groups but worst hit are the low income	H1 feedback

From the literature cited thus far, none has quantitatively assessed the socio-economic effects of flooding and water shortages across the various economic agents (see Table 2). It is, therefore, quite difficult to deduce if some income groups of people had been pushed into poverty, while others have benefited or, if all had lost. This is a gap in the existing studies that needs to be investigated

### Analysis

The enterprise analysis, in the previous section, identified the possible existence of H1, H2, H3 and H4 relationships being, simultaneously, present. Most of these studies, however, were neither conclusive enough, about the direction, nor the magnitude of the relationships. The magnitude and direction of causality, between resource degradation and poverty, remain largely unknown. More refined and detailed information of the socio-economic groups responsible for the environmental degradation, as well as their magnitude, could shed more light and guide in the design of corrective policy. For example, if H1 is the causal link, then policy should focus more on poverty alleviation than correcting market failure and power and wealth factors.

The impact analysis, on the other hand, established the H1 feedback and, probably, H5 links. Again, the literature does not give indication of the magnitude and direction of the two links. The interesting observation is that, the actions of one individual could cause the welfare of another to fall. This implies that a Pareto inefficiency exists, that requires immediate redress.

### 3. Analytical Model

To help fix ideas, we test the H5 hypothesis. We begin with a static one shot model of time allocation by a representative household<sup>4</sup> between various activities. We later extend to a dynamic model that incorporates the effects of time. (The

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<sup>4</sup> The assumption retained throughout this analysis is that the household maximises a single profit function.

motivation for the extension is provided in the next sub-section.) The link between agriculture and forest resource extraction is seen through the labour-time allocated between these activities, and there is the positive externality exerted by forest<sup>5</sup>. This link is also justified from the point of view that it is the lack of viable production activities and lack of properly defined property rights that leads to the destruction of the resource base. Each household has an endowment of time  $T_i$ , which is allocated among competing activities. The total amount of revenue received by each household, and the amount of time devoted to each activity, determine their household income status, via the respective production functions.

Perhaps the starting point is to formalize a relationship between deforestation, on one hand, and poverty, prices and tenure conditions, on the other.

Deforestation =  $f$  (poverty, prices, security of tenure).

The "representative" individual makes a decision on how to allocate his time among a number of competing economic activities. In his production choice set, he has four alternatives:

- Devote his time  $T_w$  hours offering labour for a wage or engage in other income generating activities, earning at a rate  $w$ ;
- Use  $T_A$  hours to produce food crops, and other goods, for his family consumption and sell the surplus at  $P_A$  net of cost;
- Spend his time  $T_f$  hours expanding area or cultivation in the forest. There exists a market for the forest product which, in our case is charcoal and fencing posts, sold at price  $P_f$ ;
- Invest  $T_i$  hours in land improvement changes, like terracing, fencing or application of manure on his farm.

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<sup>5</sup> Soils in tropical areas owe their productive qualities to the protective role of forests and humus from decomposing vegetation.

For consumption, the choices he can make are from goods that are produced and consumed in the family, goods purchased in the market and leisure.

Formally, the individual's problem is the maximization of total revenue from wage employment, agricultural production, and sales of forest products subject to the time constraint.

$$\begin{aligned} \text{Max} : \pi &= wT_w + P_A Q(T_A, I, \alpha) + P_F G(T_F, X) \\ &\quad (3.1) \\ \text{s.t. } T_A &= 1 - T_A - T_F - T_I : \text{ where } T_F, T_w, T_A, T_I \geq 0 \end{aligned}$$

Production of forest and crops is determined as:

$$\begin{aligned} a) h &= h(T_F, X) \\ b) Q &= Q(T_A, I, \alpha) \end{aligned} \quad (3.2)$$

Where  $h$  and  $Q$  are production in physical units,  $X$  is the forest stock,  $I$  represents knowledge in agriculture,  $I$  is the augmentation amount, and  $T$  is the time spent in each activity. The production function (3.1) is assumed concave, with positive but diminishing marginal returns for all inputs. All inputs are normal, and any pair of inputs are complimentary, ( $\pi_{ij} > 0; i \neq j$ ).

$$\frac{\partial \pi}{\partial w} > 0, \frac{\partial \pi}{\partial P_A} > 0, \frac{\partial \pi}{\partial P_F} > 0.$$

The Lagrangian associated with this maximization problem is:

$$L = wT_w + P_A Q(T_A, T_I, \alpha) + P_F G(T_F, X) - \lambda [1 - T_A - T_F - T_I - T_w] \quad (3.3)$$

At the margin, the marginal benefits, per unit of output, of the three activities, should equal the wage rate, or the shadow value of time. While not presenting the formal derivation of the comparative static results, the effects of the exogenous changes of some of the variables in the model are fairly straightforward and presented below:

1. Higher wages from a growing economy would attract people, thereby reducing forest dependence and, hence, its degradation.
2. Higher agricultural prices lead to increased profits and thus would increase forest resource destruction since individuals are induced to cut down forests, or expand into marginal land, to increase the area under crops.
3. Higher prices for forest products, would lead to more forest being destroyed for charcoal and fencing materials.
4. Relative profitability determined by higher output prices or increasing technological progress will increase relative profitability of agriculture and land under agriculture.
5. Increased augmentation, assuming that complementarity with labour, increases output.

#### The Dynamic Model

We extend the previous static model by including time. A static model neither captures the impact of time on deforestation nor its effects on income streams and, invariably, poverty. An intertemporal dimension of deforestation, on incomes and other decision parameters, is something that has either only been mentioned or hinted at in the literature. An awareness of the differences, in timing, between deforestation and incomes is a desirable first step. How exactly does the timing of deforestation influence crop production and, consequently, incomes? This question deserves a more structured approach than has heretofore been taken.

The optimal control theory suggests a framework that may serve this purpose. The model suggested is essentially a mirror image of a capital investment model, applied to a dynamic choice model of labour allocation on forestry activities. We have argued that stocks

of forest do impose a positive externality on crop production and that any decline in productivity can be attributed to declining stocks of forest. On site, soil loss, due to deforestation, causes a decline in crop growth, resulting in reduced future productivity. Over time, this loss leads to declining incomes and consequently, loss of command over market goods and services. By assuming the planning horizon to be infinite, this inter-temporal effect on poverty is incorporated. The inclusion of off-site effects is obviously a difficult problem in optimal resource management. Recent advances in non-market valuation methodology offer promise in estimating the offsite damages and incorporation in the objective function. However, that task is not undertaken here.

#### The model

The household's problem is to maximize revenues from crop production and forest extraction, less amounts spent on augmentation<sup>6</sup>. Correspondingly, the model has one state variable: the forest stock ( $X$ ), measured in total hectares. The state equation represents the growth rate of forest and its harvest by the households. It is this harvest that constrains the output from agriculture.  $X(t)$  is forest stock at any point in time,  $X(t) > 0$ , initial stock size  $X(0) > 0$ . The standard growth function for aggregate forest biomass, when no harvest takes place is given by:

$$\dot{X} = F(X, \gamma, K) \quad (3.4)$$

Where:  $X$  is the intrinsic growth of forest biomass;  $K$  is the carrying capacity; and,  $F(X)$  is the growth of biomass and is non negative, for  $0 < X < K$ .

The explicit function could be to assume a logistic growth function as follows:

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<sup>6</sup> Note that dropping wage employment argument in the objective function does not change our key results.

$$F(X(t), \gamma, K) = \gamma X \left(1 - \frac{X}{K}\right). \quad (3.5)$$

We adopt a, slightly, different notation to incorporate time as a continuous variable. We write  $T_A$  and  $T_F$  as  $L$ , in continuous time. Hence  $h = h(T_F, X)$  is the same as  $h = h(l, X)$  and  $Q = Q(T_A, l, \alpha)$  is  $Q = Q(l, l, \alpha)$  in continuous time. Note that the household allocates its labour between farming and forest extraction activities only. Crop production is given by:

$$Q = Q(L, l, \alpha)$$

Where:  $Q$  is output at any point in time and is measured in output per hectare;  $\Pi$  is a coefficient representing knowledge of agricultural techniques;  $l$  is the amount of augmentation effort (e.g. quantity of fertilizer applied or length of bunds built); and,  $L$   $\Pi$  is an interaction variable between labour time and knowledge in crop production.

The partial derivatives with respect to the arguments are as follows;

$$Q_{l,\alpha} > 0, Q_{l,\alpha l,\alpha} < 0, Q_l > 0, Q_{\Pi} < 0, Q_{l,\alpha l} > 0, Q_{\alpha} > 0, Q_{\alpha\alpha} < 0, Q_{\alpha l,\alpha} > 0, Q_{\alpha l} > 0.$$

We further assume that, the crop production function is concave, continuous and twice differentiable, in  $L$   $\Pi$  and  $l$  such that  $Q_{l,\alpha l,\alpha} Q_{\Pi} - Q_{l,\alpha l,\alpha}^2 > 0$ . There is no hired labour; the household uses its own labour (see footnote 6).

Forest harvest is given by:  $h(t) = h(X, L)$  measured in bags of charcoal or number of posts. The partial derivatives, with respect to the variables, are;

$$h_X > 0, h_{XX} < 0, h_L > 0, h_{LL} < 0, h_{LX} < 0$$

The last cross partial derivative implies that declining stocks of forest have negative impact on the marginal productivity of labour. Labour has to travel longer distances in search of forest resources.

Harvest, at any point in time, is given by  $h(t)$ , which is an increasing function of labour and forest stocks, but subject to diminishing returns.

Household revenue at any point in time is given by:

$$Y = \pi = P_A(Q(L, I, \alpha) - P_I I + P_F(h(X, L))) \quad (3.4)$$

where,  $P_A$  is the output price of agricultural output,  $P_F$  is price of market charcoal or other forest products and  $P_I$  is the price of purchased inputs. The current flow of revenue,  $Y$ , is gotten from sales of agricultural produce and forest extraction products. The stocks of forest are given at the initial dates; the control variables are  $L$ ,  $X$  and  $I$ . The objective is to maximize the discounted sum of the flow of aggregate revenue over the indefinite future. Formally, the household's maximization problem is given as:

$$\int_0^{\infty} Y e^{-\delta t} dt \quad (3.5)$$

Where,  $\delta > 0$

$$\begin{aligned} \dot{X} &= F(X, \gamma, K) - h(X, L) \\ X(0) &= X_0 \end{aligned} \quad (3.6)$$

The current Hamiltonian value associated with our maximization problem is written as;

$$H_t = P_A(Q(L, I, \alpha) - P_I I + P_F(h(X, L))) + \lambda(F(X, \gamma, K) - h(X, L)) \quad (3.7)$$

$\lambda$  is the costate variable associated with the maximization problem. It indicates the shadow price of forest stock. Recall that the theory of optimum control instructs us to choose the control variables at each date so as to maximize equation (3.7). The first order necessary conditions to the problem are written as:

$$\begin{aligned} i) \quad \frac{\partial H}{\partial I} &= P_A Q_I - P_I = 0 \\ ii) \quad \frac{\partial H}{\partial L} &= -P_A Q_{L,A} + P_F h_L + \lambda h_I = 0 \\ iii) \quad \dot{X} &= F(X, \gamma, K) - h(X, L) \\ iv) \quad \dot{\lambda} - \delta \lambda &= -(P' h_X + \lambda (F_X - h_X)) \end{aligned}$$

Transversality conditions

$$\begin{aligned} v) \quad X(0) &= X_0, \lambda(T) \geq 0 \\ vi) \quad X(T) &\geq 0, \lambda(T) X(T) = 0 \end{aligned}$$

(3.8)

The second order condition holds if our Hamiltonian is concave;

$$H_{II} H_{LL} - (H_{IL})^2 > 0$$

*Interpretation of the first order necessary conditions*

Interpretation of the necessary conditions is a routine matter. Equation (i) equates marginal benefit of an incremental increase in purchased inputs to the price of inputs. Equation (ii) equates marginal benefits of labour input, in forest extraction, to its marginal cost. It has two components: a forgone marginal benefit ( $P_A Q_{L,A}$ ) of not employing labour in agriculture and  $\lambda h_L$ , which is the opportunity cost of harvesting the resource today, as opposed to keeping it for future use. The equation also suggests that  $(P_F - \lambda) h_L = P_A Q_{L,A} > 0$ , with the implication that the shadow price of forest resource stock must be less than the price of the forest product.  $P_F$  should compensate both for the forgone

agricultural income, due to the allocation of labour to forestry and the forgone benefits from not conserving the forest for the next period.

Equation (iii) is the resource constraint, showing how the resource stocks change over time. Rearranging equation (iv) yields  $\delta\lambda - \dot{\lambda} + \lambda h_X = P_F h_X + \lambda F_X$ . The RHS is the benefit from harvesting, which comprises of two components; the direct benefits from harvesting in the current period ( $P_F h_X$ ) and the indirect benefit from incremental growth of stocks  $\lambda F_X$ . The  $\lambda$  is a price that converts the growth of forest stocks into money. The LHS term has three terms,  $\delta\lambda$  is the interest earned, if the capital had been invested in alternative investments,  $\dot{\lambda}$  is the capital gains term and  $\lambda h_X$  is the value of forgone benefits of future harvest.

#### 4.0 Comparative Statics

We linearise the equations in (3.8) and rearrange them to form a matrix B, which, we assume, is nonsingular and, therefore, has a determinant  $|B|$ . Recall that, the vector of exogenous parameters include:  $P_A$ ,  $P_F$ ,  $P_I$ ,  $\alpha$  and  $\lambda$ . We analyse the probable impact of a change in the exogenous parameters on the control variables.

$$\frac{dI}{dP_A} = -Q \{ P_A Q_{\alpha} L_{\alpha} + (P_F - \lambda) h_{L,L} \} + P_A Q_{\alpha} Q_{I\alpha} / |B| > 0 \quad (4.1)$$

$$\frac{dI}{dP_F} = -P_A h_L Q_{I\alpha} / |B| < 0 \quad (4.2)$$

$$\frac{dI}{dP_I} = P_A Q_{\alpha} Q_{I\alpha} + (P_F - \lambda) h_{L,L} / |B| < 0 \quad (4.3)$$

$$\frac{dI}{d\alpha} = -P_A Q_{\alpha} \{ P_A Q_{\alpha} Q_{\alpha\alpha} + (P_F - \lambda) h_{L,L} \} + (P_A)^2 Q_{I\alpha} Q_{\alpha\alpha} / |B| > 0 \quad (4.4)$$

$$\frac{dI}{d\lambda} = P_A h_L Q_{I\alpha} / |B| > 0 \quad (4.5)$$

Similarly we could work out other comparative statics with respect to other control variables of interest.

$$\frac{dL}{dP_A} = P_A Q_{ff} Q_{ff\alpha} Q_f / |B| < 0 \quad (4.6)$$

$$\frac{dL}{dP_f} = -P_A Q_{ff} h_f / |B| > 0 \quad (4.7)$$

$$\frac{dL}{dP_i} = P_A Q_{ff\alpha} / |B| > 0 \quad (4.8)$$

$$\frac{dL}{d\alpha} = (P_A)^2 Q_{ff} Q_{ff\alpha} - (P_A)^2 Q_{ff\alpha} Q_{ff\alpha} / |B| < 0 \quad (4.9)$$

$$\frac{dL}{d\lambda} = P_A Q_{ff} h_f / |B| < 0 \quad (4.10)$$

#### Implications from the comparative statics

Intuitively, labour allocation to forest extraction and agriculture, suggests that an increase in price of agricultural production will increase the use of purchased input, whereas an increase in price of forest product will reduce purchased input use. Increasing attractiveness of forest products implies a reduction of farming activity. A higher  $\lambda$ , (shadow price of forest biomass) increases the opportunity cost of deforestation and, therefore, reduces the labour time allocated to forest extraction. The surplus labour released from deforestation activities can be transferred to agriculture. Policy should be directed at diverting labour away from forest extraction.

An increase in the price of agricultural output leads to a higher labour allocation in agriculture, thus reducing labour use in forest extraction, and vice versa. An increase in agricultural input prices makes farming less intensive and leads to increased labour allocation to forestry. Improved knowledge of farming techniques leads to a shift in labour allocation from forest to farming. Finally, a higher shadow price of forest resource stock increases the opportunity cost of forest extraction, so that the household allocates less labour to forest extraction activities.

### 5. Conclusion

This paper surveys existing literature on poverty and deforestation and attempts to provide understanding to the links from a socio-economic and ecological perspective. The dynamic model reported is directed towards policy and empirical application. The model seeks to show the changes in income streams, over time, attributable to changes in forest stocks. The decline in ecological services offered by forests, contributes to the decline in crop productivity and, consequently, output. This invariably leads to a decline in income and the resultant command for market goods and services. The household allocates labor to various activities, based on relative profitability. A change in certain exogenous variables, like prices, can influence labor allocation in favour of forest preservation. Whether the results hold, however, is an empirical question.

### Possible problems

The ultimate goal of this paper is to empirically test the hypotheses derived therein for Kenya. However, the implementation of such a study faces some challenges. First, is the availability and quality of time series or panel data. Most of the data available covers national level, yet factors causing deforestation are relatively location-specific. Secondly, the problem as formulated is within a partial equilibrium framework. The risk with that is the failure to capture other important factors that influence the problem at hand. There is also a limitation imposed by the forest model: it does not fully capture the dynamics of forest growth.

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