

Contribution of Agriculture to Deforestation in the Tropics: A Theoretical Investigation

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Abstract

This paper compares the deforestation path taken by profit maximizing agricultural firms in tropical regions to the path that will maximize social welfare based on optimal control techniques. We set up a theoretical problem where the socially optimal deforestation path that maximizes the discounted sum of net benefit of forest land use to society diverges from that of a farmer. We arrived at this conclusion after solving for the optimal choice of deforestation for both the private farmer and a social planner. The key source of this divergence in deforestation path is that the cost of deforestation is external to the farmer. The paper concluded that the farmer's deforestation path leads to socially suboptimal outcome. Fiscal policy measures and public ownerships are recommended to deal with externalities that are inherent in forest land use.

Keywords: Agriculture, Deforestation, Optimal control

1. Introduction

Deforestation is highly endemic in developing economies most of which are located in the tropics due to their high dependence on agriculture and related activities. This calls for a critical theoretical examination of the main mechanism through which agriculture drives deforestation. This will offer an invaluable policy on how tropical deforestation can be controlled while sustaining agriculture which is the major source of livelihood for majority of the population in the tropics. This, it is hoped, will guide policy makers to protect the fauna and flora species

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associated with the forest as well as maximize the gains from the green cover to mankind.

Managing forests on sustainable basis implies the use of all the components of the forests in a way and at a rate that does not lead to a long term decline in their ability to perform all their functions, thereby maintaining the forests' potential to meet the needs and aspirations of the present and future generations (Benhin, 2006). Significant proportion of agricultural activities in the developing world occurs in the rainforest. This has resulted in a high rate of deforestation and posing a serious threat to the sustainability of agriculture in the tropics as well as life on earth. Agriculture has been noted as the major cause of forest loss, having been estimated to account for about 90 per cent of all deforestation in the tropics (Benhin, 2006). Throughout the developing world, rapid deforestation, fuelled by agricultural land use is laying waste to valuable economic assets, destroying fragile soils and accelerating desertification. According to a World Bank estimate in 1991, over 20 million hectares of forest, principally tropical rainforest, are lost each year. Of total global forest area, 47% is found in the tropical zone (Perman, *et al.*, 2003). According to Perman *et al.*, (2003), natural forests continue to be lost or converted to other uses at high rates. Between 1990 and 2000, 4.2% of the World's total natural forest area (16.1 million hectares) was lost, with most of this occurring in the tropics (Perman, *et al.*, 2003).

Whilst growing population, urbanization and poverty makes deforestation an inevitable act, its rate need to be checked especially in the tropics, where for all practical purposes, the rain forest must be considered among the class of exhaustible resources (Ehui, *et al.*, 1989; Akpalu and Parks, 2007). In spite of the widespread concern about deforestation in the tropics, little formal analysis of the socially optimal allocation of land between forest and agriculture use is available. This problem is further compounded by the lack of knowledge about the relationship between deforestation, soil erosion and agricultural productivity in the tropics. The objective of this paper is to determine the optimal use of land between agriculture and forestry in the tropics based on optimal control techniques. This will help in designing instruments for forestry policy in the tropical regions.

The rest of the paper is organized as follows. Section 2 presents the trends in agriculture and deforestation in the tropics and section 3 develops and analyzes the theoretical model for optimal land allocation between forest and agriculture in the

tropics. Section 4 discusses appropriate forestry policy instruments necessary to drive the country along the socially optimal deforestation path whilst the final section, 5, concludes.

2. Trends in tropical deforestation

In this section of the paper, we present and discuss the facts about trends in deforestation in the tropical zone. Global forests area is estimated to be over 4 billion hectares (ha) in 2010 representing 31% of the earth's total land area with an average of 0.6 ha per capita. However, distribution of forest area is uneven across countries. The Global Forest Resources Assessment¹ 2010, posit that whereas the five most forest-rich countries (the Russian Federation, Brazil, Canada, the United States of America and China) account for more than half of the world's total forest area, some ten countries (arid) have no forest at all and an additional 54 with forest cover less than 10 per cent of their total land area (FAO, 2010).

Over the years the world's forest cover has been declining at an alarming rate despite a reduction in the rate of decrease between 2000 and 2010. The FAO (2010) estimates that between the years 2000-2010, 13 million hectares of the world's forest cover were lost each year to the process of deforestation, declining from 16 million hectares per year in the 1990s. The principal agent for the high rate of deforestation, particularly in the tropics, is agriculture. However, the net forests loss in hectares is decreasing due to forest planting, landscape restoration and natural expansion of forests.

According to the FAO (2010), net change in forest area declined from -8.3 million hectares per annum in the period 1990-2000 to -5.2 million hectares per annum between 2000-2010. South America and Africa have consistently experienced reductions in their forest cover and records the highest net loss. Rates of deforestation are higher in Africa with an estimated annual rate of -0.52% per annum as compared to South America with -0.41% per annum between the years 2000-2010 (FAO, 2010). Whereas forest area in Oceania and North and Central America barely changed, Europe continued to expand its green cover albeit a slower rate than in the 1990s. Interestingly, Asia, which had a net loss of -0.10 % in the 1990s, recorded a net gain of 0.29% in forest land over the period 2000-2010. This progress is mainly attributed to the large-scale afforestation in China (FAO, 2010). Figure 1 presents a summary of trends in world forest cover.

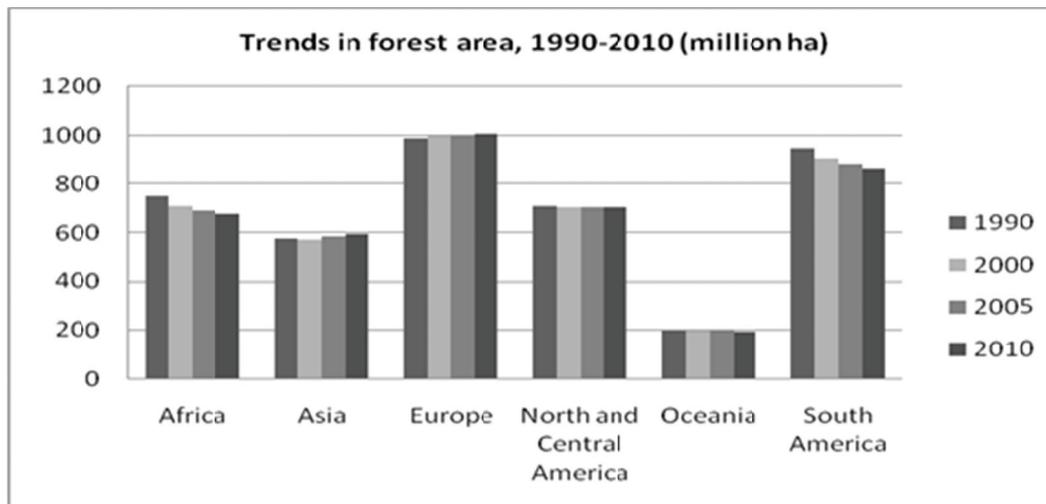


Figure 1: Trends in Forest Area, 1990-2010 (million ha)

Source: FAO, 2010 (Global Forest Resources Assessment Report)

Notwithstanding the increasing trends in deforestation rates across the geographical zones there are efforts in each region to reclaim the lost forest via afforestation. Trees planted forests are increasing and now account for 7% of total forest area (264 million hectares) globally. Between the years 2005–2010, global planted forest area surged up by about 5 million hectares per annum. Asia recorded the highest increase in afforested lands— mainly propelled by the success of afforestation projects in China. Africa, Oceania and South America however performed poorly with total forested lands less than 20 million ha in 2010 (FAO, 2010).

Comparing trends in deforestation across economic regions gives credence to the Environmental Kuznets Curve (EKC) hypothesis. According to the hypothesis, low income countries have lower demand for environmental quality relative to rich ones. This then suggests that deforestation will be more prevalent in low income economies than high income economies. Whereas the total forest area in low income countries has depreciated over the period 1990-2007, the reverse is true for high income economies. Between 1990-1997, low income (LI) countries lost -0.63 million square kilometres (sq. km) of forest cover at an annual deforestation rate of -0.78%, exceeding the global estimates by -0.20 %. Generally low and middle income countries (LMI) suffered huge losses in forest lands of about-1.52 million sq. km and an annual deforestation rate of -0.18 %. Meanwhile,

high income (HI) economies gained an increase of 0.12 million square km at an annual rate of 0.08%. Countries in the income transition zone—middle income (MI)—have also recorded some level of loss in forest cover approximately -0.89 million sq. km. The implication is that high income countries tend to demand tighter forest regulatory policies relative to their poor counterparts. Another argument is that poor countries depend heavily on agriculture, which has been tagged as the leading cause of forest loss globally.

In the European Union for instance, total forest land increased by 0.11 million sq. km compared to heavily indebted poor income countries (HIPC) countries which lost -0.64 million sq. km of forest cover. The trends in deforestation reveal that the incidence of deforestation are highest in low income countries (-0.78 p.a.) particularly in Sub-Saharan Africa (-0.65) and Latin America and the Caribbean (-0.49).

3. The model

This section presents the model and analytical results of the paper. Let X be the total land available for forest and agriculture in tropical regions, measured in hectares. In the tropics most agricultural land were originally covered by virgin rain forest. We denote the forest stock by F also measured in hectares and assume for ease of exposition that the initial values of X and F are equal implying that the total land area were initially covered by forest.

In order to produce agricultural commodities, at time t , the farmer requires labour ($L(t)$), capital ($K(t)$), purchase inputs ($Z(t)$), land ($N(t)$) and deforestation ($D(t)$). The agricultural production function takes the following form:

$$Y(t) = f[L(t), K(t), Z(t), N(t), D(t)], \quad (1)$$

where $Y(t)$ is agricultural yield (output) at time t , and $Z(t)$ is a vector of purchase inputs. Labour and capital act as complements, whilst purchase inputs act as substitutes to deforestation. The production function is assumed to be essential in labour, capital, land and deforestation, but inessential in purchase inputs. In addition to this, the production function is assumed to exhibit diminishing but positive marginal returns in each of its five arguments.

The isocost of the agricultural firm is given by equation 2. Where $C(t)$ is the total amount at time t , to be spent on all inputs, w is the agricultural wage rate, r is the rental cost of capital, χ is the price per hectare of farmland and q is the vector of prices for purchase inputs. Factor markets are assumed to be competitive so factor prices are taken as given (they are exogenous to the model) and each factor is rewarded with its marginal contribution to total output. Note that deforestation is outside the cost equation. The reason for omitting it is that the cost of deforestation is external to the firm once the labour and capital needed to clear the forest have been accounted for. The implication is that from the view point of the farmer, deforestation is the cheapest among all the inputs into production. This is the Genesis of the deforestation problem in the developing world.

$$C(t) = wL(t) + rK(t) + \chi N(t) + \sum_{i=1}^n q_i z_i \quad (2)$$

Following Ehui *et al.*, (1989), we put the tropical forest into the class of exhaustible resources. This is reasonable when the benefits of the forest is viewed broadly to include non-commercial use such as carbon store, biodiversity, option value, climate regulation and recreational amenities in addition to timber and agricultural uses. The forest stock must therefore satisfy the following dynamic equation:

$$\frac{dF(t)}{dt} = -D(t) \quad (3)$$

According to equation (3), the forest stock at any point in time decreases by the total amount of deforestation measured in hectares during the same time period under consideration. This is a typical dynamic equation to characterise the stock dynamics of an exhaustible resource.

3.1. The Farmer's Problem

The representative farmer's problem is to choose the amount of each input to maximize the discounted profit. Equation 4 spells out the farmer's problem more formally.

$$\max \pi = \int_0^T \left[pf[L(t), K(t), Z(t), N(t), D(t)] - [wL(t) + rK(t) + \chi N(t) + \sum_{i=1}^n q_i z_i] \right] e^{-\theta t} dt \quad (4)$$

This reduces to acting to maximize profit in each period. Thus, the above dynamic maximization problem can be stated in its static equivalent form as:

$$\max \pi = pf[L(t), K(t), Z(t), N(t), D(t)] - [wL(t) + rK(t) + \chi N(t) + \sum_{i=1}^n q_i z_i] \quad (5)$$

The appropriate first order conditions are given by equations 6-10. These conditions imply that the farmer employ each input to the point where the value of the marginal product of each input is equal to its price. Since deforestation is a free input in agricultural production once the labour and capital cost are taking care of, the farm set the value of marginal product of deforestation to zero. This is a clear indication that the chosen path of deforestation by the representative farmer is socially sub-optimal. This calls for public policy intervention to internalize the cost of deforestation. This is the core of the problem of deforestation in the tropical regions. Farmers have sort to increase farm yield by using more of the less expensive input, deforestation.

$$\frac{\partial \pi}{\partial L} = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial L} - w = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial L} = w \quad (6)$$

$$\frac{\partial \pi}{\partial K} = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial K} - r = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial K} = r \quad (7)$$

$$\frac{\partial \pi}{\partial N} = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial N} - \chi = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial N} = \chi \quad (8)$$

$$\frac{\partial \pi}{\partial z_i} = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial z_i} - q_i = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial z_i} = q_i \quad (9)$$

$$\frac{\partial \pi}{\partial D} = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial D} = 0 \quad (10)$$

Equation (10) confirms the assertion that in the developing world, deforestation acts as a cheaper equivalent to a good dose of fertilizer for increased agricultural production in the short run. This dependence on natural fertility is not only due to insufficient availability and high price of purchase inputs; it is also due to certain features of tropical soils which substantially limits their ability to store nutrients, as compared to temperate zones with deep soils and moderate precipitation where the soil can be used as efficient store of nutrients. The natural vegetation rather than the soil therefore becomes the most important store of fertility in most tropical areas (Benhin, 2006).

However, in as much as forests contribute to greater agricultural productivity in the short term, forest depletion reduces agricultural productivity in the long run. The reason is that many of the tropical soils owe their productive qualities to the protective role of the forest. The forest helps to speed up the formation of top soils, creation of favourable soil structure and storage of nutrients that are useful for crop production by retarding erosion and silting and regulating stream flows. This brings to the fore the need to choose deforestation path that guarantees the sustainable use of the forest. Next, we derive the socially optimal condition for deforestation in the tropics.

3.2. *The Social Planner's Problem*

Now consider a benevolent social planner who wishes to maximize the discounted value of net revenues from agriculture subject to the dynamics of the forest stock. Thus, the planner maximizes equation (4) subject to equation (3). The current value Hamiltonian for the dynamic optimization problem facing the planner is:

$$H = pf[L(t), K(t), Z(t), N(t), D(t)] - [wL(t) + rK(t) + \chi N(t) + \sum_{i=1}^n q_i z_i] - \lambda D(t) \quad (11)$$

The application of Pontryagin's maximum principles yields the following necessary conditions that must be satisfied along an optimal time path.

$$\frac{\partial \pi}{\partial L} = 0 \Leftrightarrow p \frac{\partial f(\cdot)}{\partial L} - w = 0 \Leftrightarrow p \frac{\partial f(\cdot)}{\partial L} = w \quad (12)$$

$$\frac{\partial \pi}{\partial K} = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial K} - r = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial K} = r \quad (13)$$

$$\frac{\partial \pi}{\partial N} = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial N} - \chi = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial N} = \chi \quad (14)$$

$$\frac{\partial \pi}{\partial z_i} = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial z_i} - q_i = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial z_i} = q_i \quad (15)$$

$$\frac{\partial \pi}{\partial D} = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial D} - \lambda = 0 \Leftrightarrow p \frac{\partial f(.)}{\partial D} = \lambda \quad (16)$$

$$\frac{\dot{\lambda}}{\lambda} = \theta \quad (17)$$

As can be seen from the first order conditions of the planner's problem, equations 12-15 are exactly the same as equations 6-9 in the farmer's problem. The planner employs each input up to the point where the value of marginal product of the input equal to its price. However the two entities, (the farmer and planner) defer on their respective optimal choices for the amount of deforestation. Whilst the farmer deforest until the value of marginal product of deforestation is zero (equation 10), the planner only deforest up to the point where the value of marginal product of deforestation is equal to the marginal social cost of (λ) of deforestation (see equation 16). According to equation (17), the marginal social cost of deforestation grows at a rate equal to the social rate of discount. The implication of this is that impatient societies with high discount rate will deplete their forest stock faster and hence have their marginal social cost of deforestation increasing at an exponential rate.

The marginal social cost of deforestation can be very large as the forest stock reduces. The social cost of deforestation also rest heavily on the weight the society puts on non-timber and agricultural uses of forest such as soil and water control, habitat support for biologically diverse system of animal and plant populations, recreational and aesthetic amenities, wilderness and existence/option values and climate control functions of the forest. In the tropics, it turns out that

the non-commercial uses of the forest carries much weight; since the tropical forest is non-renewable within any reasonable biological and economic time scale. Moreover, in the developing world, the demand for forest resources for commercial purposes is far higher than non-commercial uses such as recreational and aesthetic. This then suggest that poor regions (most of which are in the tropics) will tend to have high rate of deforestation than their rich counterparts.

This means that the negative externality caused by tropical deforestation can be very large resulting in a significant wedge between the socially optimal rate of deforestation and the optimal path taking by the private farmer. There is therefore the need for public policy intervention to internalize the externality caused by deforestation. Relevant policy instruments to control deforestation are discussed in the next section of the paper.

4. Policy instruments

In this section of the paper we discuss the policy instruments that can be used to internalize the externalities in the forestry sector particularly in the tropical regions. Where forestry serves multiple uses, government might use fiscal policy instruments, mainly, taxes and subsidies to internalize the externalities inherent in the forestry sector in order to ensure efficient and sustainable utilization of forest lands. Forest management can be improved by imposing a Pigouvian tax of λ per hectare of forest land deforested for crop production. The imposition of the tax will raise the cost of deforestation and push the rate of deforestation towards the socially optimal rate. With the increase in deforestation cost, crop yield could be maintained by employing more purchase inputs.

The next policy instrument suggests itself. We could achieve Pareto improvement in forest land use by taxing agricultural inputs (labour and capital inputs such as chainsaw, axe etc.) that are complements to deforestation and use the proceeds to subsidize inputs (eg. fertilizers, pesticides etc.) that served as substitutes to deforestation. However, a discriminatory tax on agricultural labour is not possible in practice. Subsidizing reforestation of degraded and marginal lands that is currently unsuitable for crop production will also be welfare improving. Though the biodiversity loss of clearing natural forests cannot be regained, reforestation can restore soil nutrient, help in carbon absorption and local climate regulations, among other things.

Where non-timber values are large and their incidence is greatest in mature forest as is the case in the tropical region in general, no felling may be justified. Government might seek such an outcome through fiscal incentives, but is more likely to do so through public ownership. Forest management problems are further compounded by international spill overs in forestry. Many of the non-timber values of forest resources are derived by people living in other countries. Many of the externalities associated with tropical deforestation cut across national borders (e.g. global climate change). This implies that there are limits to how much an individual national governments can do to promote efficient and sustainable forest land use. International concerted action is therefore a prerequisite of efficient and sustainable forest land use.

5. Conclusion

This paper investigated the conditions that must be satisfied along an optimal deforestation path of an exhaustible resource with special reference to tropical forest. The paper revealed that the path of deforestation that will be taken by the social planner whose objective is to maximize the discounted sum of net benefits of forest land use diverges from the path of deforestation taken by a representative farmer. The divergence is to do with differences in weight that is put on the non-commercial uses of the forest land by the individual farmer on one hand and, society on the other hand. Consequently, the optimal path of deforestation taken by the farmer yields outcome that is socially suboptimal. To deal with these, public policy interventions such as the use of Pigouvian tax and subsidies, public ownership, non-felling and internationally concerted action were recommended.

Notes

1. The Global Forest Resources Assessment report is a 5 year interval report commissioned by the Food and Agriculture Organization.

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