POVERTY AND THE MANAGEMENT OF NATURAL RESOURCES: A MODEL OF SHIFTING CULTIVATION

By:

Edmund M. Balsdon
Department of Economics
San Diego State University

JEL Classifications: Q1, Q2
Key Words: Poverty, Shifting Cultivation, Deforestation, Soil Productivity

Abstract

It is frequently asserted in the environment/development literature that severe poverty *causes* the neglect of worthwhile investments, resulting in deforestation and other resource degradation. While microeconomic theory does suggest a relationship between poverty and the evaluation of investments, the environmental impact is not so simple. This paper develops a dynamic theory of "shifting cultivation," with special attention to an environmental impact variable: the length of time a given field is cultivated before a shift to the next. The model indicates that poverty reduction will lead in some ways to accelerated extraction of a natural resource, but also to a longer extraction period. The results therefore provide support for claims of an indirect environmental benefit from the primary goal of alleviating rural poverty. The impact of discount rates, prices, and other parameters are also explored.

For helpful comments on earlier drafts of this paper I am grateful to Robert Deacon, Charles Kolstad, Lia Roberts, seminar participants at UC Santa Barbara, the University of Colorado, San Diego State University, the 2000 CWERE Workshop, and two anonymous referees. Remaining errors are mine.

Author address: Department of Economics, San Diego State University, San Diego, CA 92182-4485.
Tel 619.594.5492. Email ebalsdon@rohan.sdsu.edu

Poor families often have to meet urgent short-term needs, prompting them to "mine" natural capital through, for example, excessive cutting of trees for firewood and failure to replace soil nutrients. *World Development Report* (1992), page 7.

1 Introduction

The causes of environmental degradation in developing countries can be difficult to disentangle from the challenges of economic development. For example, while the evidence clearly points to the conversion of forest land to agricultural uses by small to medium-sized farmers as a significant *proximate* cause of deforestation, it is also commonly asserted that such environmentally destructive activity is *ultimately* caused by poverty.[1] Traditional agricultural practices, called "shifting cultivation" throughout this paper, are characterized by short periods of cultivation, long periods of fallow, a deficiency of investments in agricultural capital, and rapid deterioration of soil quality and yields. The land left to fallow can also be highly eroded, with the remaining soil requiring a longer period of regeneration before the land is again suitable for cultivation. Economists point out that the land intensity is driven largely by the fact that forest land and biomass are the relatively abundant resources, some even describing the process as "nutrient mining" [see Lopez (1994) and (1997)].

The excerpt above from the World Bank's widely read publication represents a characteristic view of the connection between poverty and environmental degradation: poverty itself causes high discount rates, which in turn cause not only more poverty but environmentally destructive agricultural practices. The World Commission on Environment and Development (1987, the "Brundtland Report") also strongly asserted such a relationship:

Poverty reduces people's capacity to use resources in a sustainable manner; it intensifies

[1]See, for example FAO (2000). Angelsen (1995) reports estimates of deforestation in developing countries due to this process in a range from 45 to 60%. For a further review of the evidence. See also Southgate, et al. (1991).

> pressure on the environment. (Page 49)
>
> But poverty itself pollutes the environment, creating environmental stress... Those who are poor and hungry will often destroy their immediate environment in order to survive: They will cut down forests; their livestock will overgraze grasslands; they will overuse marginal land..." (page 28)

The clear implication is that resource conservation requires patience, and the poor are impatient. Schneider, et al (1996) describe the destructive effects of '*Imediatismo*', a culture of Brazilian frontier farming that demands immediate returns to investment projects. For compelling empirical evidence regarding a poverty-discounting relationship in developing countries, see Pender (1996) and Holden et al (1998).[2]

These authors may be referencing standard capital theory in describing this relationship, albeit not always explicitly. Where credit is constrained (as it surely is where shifting cultivation is practiced), poverty affects a decision-maker's intertemporal marginal rate of substitution, and therefore the manner in which investments are evaluated. Since the marginal utility of consumption is highest when consumption is very low, a dollar invested carries a higher opportunity cost for the (credit constrained) poor, who in turn neglect worthwhile investments. However, closer inspection reveals

[2] The issue of poverty and discounting more generally has drawn significant attention from economists. Fisher (1930) drew "willingness lines" that were steep close to the origin to account for what he considered a fundamental behavioral regularity: "A small income, other things being equal, tends to produce a high rate of impatience, partly from the thought that provision for the present is necessary both for the present itself and for the future as well, and partly from lack of foresight and self control," *Theory of Interest* (1930). More recently, Becker and Mulligan (1997) model time preference as endogenous; they suggest that patience requires the ability to imagine and appreciate the future, which in turn requires the expenditure of resources. Alternative causality, advanced by Lawrence (1991), is that short-sighted decisions lead to lower permanent income; impatience is, after all, the tendency to forego current sacrifices that would lead to worthwhile payoffs over time. "[I]mpatient individuals may prefer jobs with flat wage paths, as opposed to careers that promise high wages only after periods of training or education (a period during which very low wages are earned)." (Lawrence, pg. 55). "I contend that the most sensible explanation is that the slower consumption growth of the permanently poor reflects their greater 'impatience' for consumption."(pg. 72). Other econometric studies of the relationship include Hausmann (1979), who finds significantly higher implied discount rates for low income individuals in the purchase of home appliances, and Kurz, et al (1973), who find an enormous difference in implied discount rates between low income blacks (80%) and educated, middle class whites (18%).

that the impact on resource conservation of this logic is not as straightforward as these quotes suggest. To see why, consider the effect of a wealth transfer in the form of a perpetuity independent of farm activity, so that household consumption rises by an equal amount in the current and all future periods. Such a wealth shift reduces marginal utility everywhere along the uneven path of consumption traveled by the shifting cultivator, but the impact is greatest where consumption is lowest. If farm income is rising over time (consumption is relatively low today) the wealth effect would encourage conservation by lowering the opportunity cost of delayed consumption. Yet, is not exactly *patience* that poverty alleviation promotes. If farm income is falling, the wealth effect would actually discourage conservation, since bolstering low future consumption becomes less urgent. Rather, it is greater *tolerance for unequal consumption across time* that is permitted with the alleviation of poverty.

So, which is shifting cultivation – an increasing or decreasing consumption path? The definition of shifting cultivation offered in the opening paragraph included "deterioration of soil quality and yields", which suggests the second case. More accurately, shifting cultivation produces a *cycle* of consumption, as in the time series represented in Figure 1. When yields are low toward the end of each period in this cycle, yields are actually increasing as the farmer looks to the beginning of the next period. In this context, the effect of a wealth transfer on the management of natural resources is not obvious.

Figure 1 near here

We see the expectations at the World Bank and elsewhere are that raising the incomes of poor farmers, while an undeniable development goal in itself, would also drive a transition toward better farming practices, and ultimately more sustainable land use in developing countries. From Holden and Binswanger (1998): "[P]overty reduction itself or profit-increasing reform may reduce the intertemporal externality, because the discount rates of the poor will decline as incomes increase." But the theoretical basics indicate that the environmental impacts of "poverty reduction itself" are more subtle. Should we expect a rise in income, living standards, or wealth, *ceteris paribus*, to provide an environmental dividend in the form of better "stewardship" of land, and therefore less pressure for forest land conversion to agriculture? The model presented in the remainder of this paper is dedicated to this question.

2 Model

The model owes features to Barrett (1992), Lewis and Schmalensee (1979), Grepparud (1997), Shivley (2001), Batabyal and Lee (2003). It is presented in two parts, reflecting a recursive nature of the management choices involved. Section 2.1 covers the management of a resource stock (soil productivity) within a single cultivation period of fixed length. I assume throughout that the area of land cultivated, and its embodied resource endowment, are determined by household labor supply and other variables that are treated here as exogenous. The environmental impact of resource management decisions then derives strictly from the length of the period during which each field is cultivated before being left to fallow, a choice modeled in Section 2.2. That is, if A is the area of land cultivated in each period of length T, and F is the length of a sufficient fallow period, the long-run land requirement is on the order of $A\,(1 + F/T)$. The variables A and F are not modelled here. The focus of the paper is T: a shorter cultivation period, all else equal, leads to greater long run demand for the conversion of forest land to agricultural use.

2.1 A single cultivation period

The management of an endowed resource stock over a fixed period $(0, T)$ is a classic problem of optimal control [see Clark (1990) and Chiang, (1999)]:

(1) $v = \int_0^T u\left[c(t)\right] e^{-\delta t} dt$

(2) $c(t) = N + px(t)$

(3) $\dot{S}(t) = g\left[S(t)\right] - x(t)$

(4) $S(0) = S_0$; $S(t) \geq 0$.

The variable S represents the stock of soil productivity remaining at time t, and x represents extraction, in the form of agricultural output. The units of x and S are defined so that one extracted unit of the resource stock always yields one unit of agricultural output. The parameters p and N represent the output price and non-farm income, respectively, so that c is household consumption. Non-farm income is a constant flow, like the perpetuity discussed in the Introduction.[3] The function $u\left[\cdot\right]$ is utility with the usual properties, and time preference is captured by δ. The household objective (for now) is to maximize (1) over the period $(0, T)$ subject to the constraints in $(2) - (4)$.

I consider three types of resource renewability, as expressed through the function $g\left[\cdot\right]$ in (3):

i) $g\left[S(t)\right] = 0$,

ii) $g\left[S(t)\right] = iS(t)$,

[3] Non-farm income, N, is the variable through which poverty alleviation is explored in the paper. An increase in N provides a "pure" wealth effect precisely because it increases consumption uniformly in the present and future. For this reason it remains quite abstract, particularly in that this approach ignores opportunity costs associated with allocating household resources between farm and non-farm activities. Changes in N can be seen as due to macroeconomic shocks that affect overall well-being without changing the relative returns to these activities, or direct from transfer payments from government.

iii) $g[S(t)] = r\left[\bar{S} - S(t)\right]$,

where i and r are natural growth rates, and $\overline{S}$ is a natural carrying capacity of the resource stock. The renewable resource models *ii*) and *iii*) allow for the natural regeneration of soil productivity, adding an additional feature of investment within a cultivation period. The non-renewable resource model *i*) can be regarded as a special case of either *ii*) or *iii*).

Equation (4) specifies the cultivated land's resource stock endowment, S_0, and a constraint that the stock cannot at any point be negative. The last is more relevant in this model than typical because of N, a consumption "cushion" that assures the marginal utility of consumption is finite even with exhaustion. It can appear attractive under these conditions to accumulate a debt of S during the period, then replace it ($x < 0$) as T approaches. To impose $S(t) \geq 0$ and rule out this absurdity, the usual Hamiltonian is modified with a Kuhn-Tucker constraint [see Clark (1990)].

When this non-negativity constraint on S is not binding, the well-known solution to this problem is characterized by a "no arbitrage" condition: the marginal utility of consumption rises at the rate of time preference plus any physical return on the resource stock, assuring that the discounted value of marginal utility is equal at every moment in the time interval:

(5) $$\eta(t)\dot{c}(t) = -\left(\delta - g'\right),$$

where $g' \equiv \partial g/\partial S$, which can take the values 0, i, or $-r$, and $\eta(t) \equiv -u''(t)/u'(t) > 0$. The somewhat more difficult case with a binding non-negativity constraint on S is outlined in some detail below.

That the optimal extraction and consumption paths are declining over the period is in doubt only for model *ii*), where it requires $\delta > i$. Since ever-increasing yields are a poor model of shifting cultivation, this condition is assumed. Using $p\dot{x} = \dot{c}$,

$$(6) \qquad \frac{d\dot{x}}{dN} = \frac{(\delta - g')\,\eta'}{p\eta^2} < 0.$$

As the sign of (6) depends only on the sign of $\eta' \equiv \partial\eta/\partial c$, we see that this fundamental feature of utility is decisive in the effect of N on the rate of extraction of the resource. It is therefore worth carefully considering $\eta(t)$, and whether it is increasing or decreasing in consumption. This measure is simply the percentage change in marginal utility, evaluated at the level of consumption in time t: the capital theory analog to Pratt's measure of (absolute) risk aversion. Here it captures aversion not to risk, but to unequal consumption over time. The very nature of poverty seems to require that $\eta' < 0$. One's willingness to forego \$100 today for a certain return of \$150 in six months depends on the proportion of current consumption the \$100 represents. The short and secure 50% return is not worthwhile if the \$100 is needed to avoid severe deprivation now. As discussed in the Introduction, it is not exactly patience that poverty affects: by similar logic, a household would accept a zero or negative return on savings to avoid extremely low consumption in a future period. More accurately, it is a greater tolerance for unequal consumption across time that is permitted with the alleviation of poverty. In the context of equation (6), higher N lowers marginal utility throughout $(0, T)$, but does so most in the part of the period where consumption is lowest (the end). In response, the optimal extraction path becomes steeper (more negative), indicating more rapid depletion of the resource.

The usual transversality condition assures the resource stock will be exhausted. Moreover, Section 3 will reveal that when the period length is chosen optimally, the last of the resource is extracted at T, and the non-negativity constraint on S is not binding. The possibility of early exhaustion is important for characterizing that optimal choice, however, so it is worth some attention here. If the period length T is sufficiently long given the parameters, extraction proceeds as described in (5), yielding constant discounted marginal utility, but the resource stock is exhausted at date $\tau < T$.[4] Beyond τ the non-negativity constraint on S becomes relevant, since the condition in (5) is met only by "borrowing" S and repaying the debt as T approaches. Instead, the non-negativity constraint imposes $x(t) = 0$, $c(t) = N$, and $S(t) = 0$ for $t \geq \tau$.

Complete characterizations of the time paths of c, x, and S, are derived in Appendix A1 assuming $u(c) = \ln(c)$. This functional form obeys the feature of utility that has been asserted: $\eta(t) = 1/c$, so $\eta' < 0$. Figure 2 presents time paths for x and S for the following parameter values $p = 1$; $\delta = .2$; $S_0 = 25$; $g' = 0$; and $T = 10$. For each variable, the two paths are for $N = 1$ (solid line) and $N = 2$ (dashed line). In 2a, as anticipated, the increase in N causes the extraction path to become everywhere steeper: more is extracted toward the beginning of the period and less toward the end. By reducing the farmer's aversion to unequal consumption over time, the wealth effect of higher N discourages conservation in the face of a declining consumption path, and the result is more rapid depletion of the resource. This is also reflected in the shift in the time path of S in 2b, where the resource stock is lower throughout the period when N is larger.

Figure 2 near here

The model to this point has not found that poverty reduction will encourage resource conservation in the context of shifting cultivation, but the opposite. In lowering the resource manager's aversion to unequal consumption over time, an increase in non-farm income should actually accelerate resource extraction. However, this single cultivation period problem has treated the length of the period, T, as given. As presented at the top of this section, this period length is ultimately the environmental impact variable. I turn now to this choice.

[4] The variable τ is a function of the other parameters in the model, but *not* of T itself. Rather, it is the value of T that solves $x(T) = S(T) = 0$ in the unconstrained solution.

2.2 Optimal cultivation period length

Assuming the land available for cultivation is of uniform quality, and that prices and other parameters in the model are stationary from one period to the next, the infinite horizon objective function is:

$$(7) \qquad V(T) = (v - z) + Ve^{-\delta T} = \frac{v - z}{(1 - e^{-\delta T})}.$$

The parameter z, measured in the same units as v, represents the fixed costs of acquiring, clearing, and preparing a new field for cultivation. Such costs are necessary for an optimal rotation of fields to exist as observed with shifting cultivation; otherwise, the optimal strategy in managing land in the presence of declining yields would be to extract all productive value at once. Instead it will be optimal to manage a field so as to spread out these "shifting costs" associated with acquiring and clearing land.[5]

As written, (7) mirrors the objective function in a Faustmann optimal rotation age problem, and an understanding of the solution to that classic problem can guide our intuition here. As with the Faustmann problem, the choice of T involves balancing the marginal costs and benefits of extending a harvesting end date. More specifically, the marginal cost of delaying the "shift" consists principally of further discounting the returns due in the remainder of the cycle. The problem here is more complex for a couple of reasons. First, extending the cultivation period affects not only what is extracted of the resource at time T, but the entire extraction path. Second, the objective function here is discounted *utility*, which lends the critical desire to smooth consumption.

Proceeding with the same functional form for utility, $u(c) = \ln(c)$, Appendix A2 derives the

[5] It is for simplicity that z enters as a fixed utility cost, rather than a variable cost measured in consumption units.While this parsimonious treatment of shifting costs is rather abstract, a more realistic model (it is reasonable to suspect that shifting costs could be function of not only of T, but of the other parameters in the model) would add a great deal of complexity to an already complex model, with little obvious impact on the central question.

following:

$$(8) \qquad V(T) = \frac{\ln N - \ln \theta(\overline{T})}{\delta} + \frac{h(\overline{T}) - z}{(1 - e^{-\delta T})},$$

where $\overline{T} = \begin{cases} T \text{ for } T \leq \tau \\ \tau \text{ for } T > \tau. \end{cases}$ As defined in appendix A1, the function θ is the optimal proportion $N/c(T)$ in the unconstrained solution. For given values of the parameters, θ is increasing in T as end-of-period extraction falls. This function also provides a ready definition of τ: $\theta(\tau) \equiv 1$. The non-negativity constraint is imposed with the definition of $\overline{T}$, so that $\theta(\overline{T}) \leq 1$. Consumption at the end of each period, $c(T) = N/\theta$, is the minimum level in the cycle. The first term in (8) represents the discounted utility of this baseline level of consumption. The function $h(T) \equiv (1 - g'/\delta)\left(T - \int_0^T e^{-\delta t} dt\right)$ captures the variable component of utility associated with declining consumption within each period. Finally, since z is a fixed cost, its impact on the objective function depends on how frequently it is incurred. The denominator $(1 - e^{-\delta T})$, increasing in T, reflects this frequency.

Appendix A2 also derives:

$$(9) \qquad \frac{\partial V}{\partial T} = \frac{z - f(\overline{T})}{(1 - e^{-\delta T}) \cdot \int_0^T e^{\delta t} dt}.$$

In (9), z represents the marginal benefit of extending the cultivation period (because z is delayed), and $f(T) \equiv h(T) + (1 - \theta) \int_0^T e^{-\delta t} dt$ represents marginal cost. This function captures both the delay of the subsequent cultivation period and lower consumption due to the extra conservation compelled by a longer period. Appendix A2 demonstrates that $\partial f / \partial T$ is positive for $T < \tau$, and zero for $T \geq \tau$, as in Figure 3. Where $f = z$, (12) is zero and, subject to a second-order condition, the objective function is maximized. The optimal period length, T^*, is depicted in Figure 3 by the intersection of the f curve with z. Notice, however, that if $z > f(\tau)$ these two curves never intersect, and $\partial V / \partial T$ is always greater than zero. The second-order maximum condition and the possibility of no interior solution for T^* are explored for the remainder of this section.

Figures 3 and 4 near here

The two possible shapes for V are depicted in Figure 4. Which shape (whether or not V has an interior maximum value) depends on the sign of $z - f(\tau)$. When $z < f(\tau)$, V increases from $V(0)$ to a maximum where $z = f(T^*)$. Beyond this point, $z - f(\overline{T}) < 0$, and V is falling. Formally, the second-order maximum condition is satisfied in this case because:

$$(10) \qquad \frac{\partial^2 V(T^*)}{\partial T^{\,2}} = \frac{-\partial f/\partial T}{(1 - e^{-\delta T}) \cdot \int_0^T e^{\delta t} dt} < 0.$$

In contrast, from (9) we see that when $z > f(\tau)$, the slope of V is always positive. This case is represented by the lower path in the Figure 4, which approaches $(\ln N)/\delta - [z - f(\tau)]$ as $T \to \infty$. Notice that $T = \infty$ is worse than never beginning to extract the resource at all. If the household consumes only N, the objective function is $V(0) = (\ln N)/\delta$. The relationship between z and $f(\tau)$ therefore identifies a shut-down condition: when $z > f(\tau)$, the household cannot profitably manage their resource endowment, and will rely on off-farm economic activity for income. When $z < f(\tau)$, the maximized objective function is $V(T^*) = \frac{1}{\delta}[\ln N + (\theta^* - 1) - \ln \theta^*]$. This is greater than the shutdown utility of $(\ln N)/\delta$, since $(\theta - 1) > \ln \theta$. The shut-down condition assures that $T^* \leq \tau$, which in turn assures that the non-negativity constraint on S is not binding when the period length is chosen optimally.

3 Results

The shut-down condition simplifies the investigation into how the model's parameters influence the choice of T^* by permiting a focus on interior solutions. The comparative static results presented here are from the total derivative of $f(T^*) = z$. Full derivations are available from the author upon request. First, the role of z is straightforward, as expected, and can be seen in Figure 3. If this parameter is zero, the model collapses to $T^* = 0$. A positive z provides the incentive to extract the resource in a manner that will limit the burden of these shifting costs. In the Figure it is clear that T^* increases as z increases, and the shut-down condition applies if z becomes sufficiently high.

$$\frac{dT^*}{dz} = \frac{1}{\partial f/\partial T} > 0. \tag{11}$$

The sign of this result relies only on an upward sloping marginal cost function, f, which is demonstrated in Appendix A2. In areas where land titling and other property rights are poorly defined, especially if forest land available for conversion to agriculture is not particularly scarce, z may not include costs associated with formal land acquisition. We see here that incomplete property rights, to the extent that they result in some acquisition costs being ignored by land users, can result in shorter periods of cultivation.

Now to the central question: how does poverty alleviation affect the optimal length of the cultivation period and, through this choice, demand for agricultural land in the long run? An increase in N shifts f downward, and therefore *increases* the optimal period length:

$$\frac{dT^*}{dN} = \frac{-\partial f/\partial N}{\partial f/\partial T} = \frac{\theta^2 p S_0 e^{-(\delta+g')T}}{N^2 \cdot \partial f/\partial T} > 0. \tag{12}$$

After the earlier finding that higher N results in a steeper within-period extraction path, this result may seem counter-intuitive. Why does the same change result in what appears to be greater "patience" or "conservation" in the choice of T? The answer lies in the fact that at the end of a cultivation period the consumption path is actually *increasing* as the farmer looks beyond the impending shifting costs to the beginning of the next period. The marginal cost of extending the period is sensitive to N because the marginal utility of consumption is highest just before the shift. An increase in N lowers marginal utility at T *more* than marginal utility at the beginning of the next period, where consumption is relatively high. The now lower marginal cost of extending the period encourages the farmer to further delay z. To take a wider view, refer again to Figure 1. There are two ways in which variance in consumption can increase over the cycle: (1) the extraction path can become steeper within each period of given length; and (2) the period length can increase. Consistent with the view that poverty alleviation permits greater tolerance for unequal consumption over time, this model finds that the shifting cultivator would respond with both of these changes in response to an increase in N.

Figure 5 and Table 1 near here

Comparative statics are presented below for the other parameters in the model and summarized in Table 1. A view of the impact of various parameter changes is also represented in Figure 5. An increase in the price of agricultural output, while certainly also a source of poverty alleviation, has the opposite effect on the optimal length of the cultivation period:

$$(13) \qquad \frac{dT^*}{dp} = \frac{-\partial f/\partial p}{\partial f/\partial T} = \frac{-\theta^2 S_0 e^{-(\delta+g')T}}{N \cdot \partial f/\partial T} < 0.$$

The difference between this change and "pure" poverty alleviation from N is in the impact on the marginal cost of extending the period. An increase in N did not affect farm profit, only the tolerance for unequal consumption over the cycle. In contrast, a higher p increases the value of farm yields, and therefore the marginal cost of delaying the beginning of the next period and its higher yields. Similar reasoning leads to the same conclusion regarding S_0:

$$(14) \qquad \frac{dT^*}{dS_0} = \frac{-\partial f/\partial S_0}{\partial f/\partial T} = \frac{-\theta^2 p e^{-(\delta+g')T}}{N \cdot \partial f/\partial T} < 0$$

The natural growth rates i and r have generally intuitive effects on the choice of T:

$$(15)\qquad \frac{dT^*}{dg'} = \frac{-\partial f/\partial g'}{\partial f/\partial T} = \frac{\frac{\partial \theta}{\partial g'} \int_0^T e^{-\delta t} dt + h(T)/(\delta - g')}{\partial f/\partial T} > 0.$$

As $g' = i$ or $-r$, this result implies $dT^*/di > 0$ and $dT^*/dr < 0$. In model *ii*), the parameter i represents a positive return to conservation of the resource stock. A larger i therefore encourages conservation, and results in a longer cultivation period. In model *iii*), the parameter r represents exactly the opposite: an additional return to *extraction*. A higher r consequently encourages more rapid extraction, and a shorter cultivation period.

The impact of a higher δ is not as straightforward:

$$(16)\qquad \frac{dT^*}{d\delta} = \frac{-\partial f/\partial \delta}{\partial f/\partial T} = \frac{-2\int_0^T e^{-\delta t} dt \cdot \int_0^T \left(\frac{(1-e^{-\delta t})}{(1-e^{-\delta T})} - \frac{t}{T} \right) dt \cdot (g'/\delta - \theta)}{\partial f/\partial T}.$$

If δ increases, the farmer further discounts future consumption relative to current consumption. This leads to a combination of effects on the optimal choice of T, and their net effect is not always clear. First, a higher discount rate encourages a steeper consumption path within each period, which feeds back to a shorter cultivation period. This effect competes with a second, more direct effect. The choice of T reduces fundamentally to a weighing of the cost of shifting fields, z, with the subsequent improvement in yields in the next period. Because this improvement occurs only *after* incurring shifting costs, a less patient individual discounts it more and will tend to delay the costs further. An impatient individual may be an accidental conservationist, because they are reluctant to undertake the shifting costs that lead to higher average yields. Since $\frac{(1-e^{-\delta t})}{(1-e^{-\delta T})} \geq \frac{t}{T}$, the middle term in (16) is positive and the sign of the effect depends on the sign of $g'/\delta - \theta$. In models *i*) and *iii*), this term is always negative, and a higher discount rate results in a longer cultivation period. For model *ii*), it is ambiguous.

4 Conclusion

The destructive path of shifting cultivation and the persistent impoverishment of its practitioners has many in the international development community hopeful for an environmental dividend to the primary goal of reducing poverty. "Alleviating poverty is both a moral imperative and essential for environmental sustainability," claims the 1992 World Development Report (page 25). The issue is characteristic of environment-development relationships, with forceful claims about the effect of higher incomes on the environment in either direction, but still only an evolving understanding of their complexity. This paper has contributed to that understanding by scrutinizing the theoretical basis for claims that poverty *per se* causes short-sighted decisions and consequently environmentally destructive farming practices.

The analysis began with a straightforward prediction of capital theory that poverty, when combined with constrained access to credit, should affect the manner in which investments are evaluated. This is because poverty is synonymous with high marginal utility of consumption, and this marginal utility is central to one's willingness to trade off current and future consumption. A general increase in consumption lowers marginal utility, but not equally: it falls most where consumption is lowest. This change in the weighting of current and future consumption can clearly affect the management of natural resources, but a presumption that this will always lead to more conservation is premature. What poverty alleviation really accomplishes is an increase in tolerance for unequal consumption over time. This greater tolerance encourages conservation when the manager of that resource faces an increasing consumption path, but the opposite when consumption is declining.

In this light, a significant challenge of the model was to adequately capture the cycle of consumption produced by a regime of shifting cultivation. Yields from a single field are decreasing over the period in which it is cultivated, and the model finds that poverty alleviation in fact accelerates resource extraction within a cultivation period. The key environmental impact variable, however, is the length of that period: a farmer that continuously cultivates each field for a longer period will demand less agricultural land in the long run. Here, the model finds that poverty alleviation does encourage conservation. The model also revealed a few surprises regarding the impact of other parameters on the optimal cultivation period length. Higher prices or productivity for agricultural output, while certainly also a source of poverty alleviation, would have the opposite impact on conservation. Given that poverty is frequently addressed through price controls, this is an important distinction. An important distinction between the effects of poverty alleviation and "patience" was highlighted by the comparative statics results for time preference.

This paper explored a fundamental relationship between poverty and conservation effort by individual resource managers. Given this limited scope, the household in the model faced a fixed competitive price not only in the output market, but also implicitly for land and labor. A more complex picture may result from the endogeneity of prices with widespread changes in wealth for a rural community.

5 Appendix

A1:

The condition in (5) for log utility implies $\dot{c}/c = -(\delta - g')$, or $c(t) = c_0 e^{-(\delta - g')}$. The time path for c, found by substituting (2) into (3) and integrating both sides:

$$(A1.1) \qquad c(t) = \left(\frac{pS_0 + N \int_0^T e^{-g't} dt}{\int_0^T e^{-\delta t} dt} \right) e^{-(\delta - g')t}.$$

Let $\theta \equiv \dfrac{\int_0^T e^{\delta t} dt}{(pS_0/N)\, e^{g'T} + \int_0^T e^{g't} dt}$, so that we have:

$$(A1.2) \qquad c(t) = (N/\theta)\, e^{(\delta - g')(T-t)}, \text{ and}$$

$$(A1.3) \qquad x(t) = \frac{c(t) - N}{p} = (N/p)\left(\frac{e^{(\delta - g')(T-t)}}{\theta} - 1\right).$$

From $(A1.2)$ we see that $\theta = N/c(T)$, which provides a handy way to identify τ. Since τ is the date at which extraction falls to zero, $c(\tau) = N$ and $\theta(\tau) \equiv 1$. As long as $T < \tau$, resource extraction is positive at the end of the period, so $\theta < 1$. Where $T > \tau$, the (unconstrained) time paths in for c and x described in $(A1.2)$ and $(A1.3)$ are invalid, as they imply negative extraction at the end of the period ($\theta > 1$). The non-negativity constraint on S requires that we impose:

If $T > \tau$:

$$(A1.4) \qquad c(t) = \begin{cases} N \cdot e^{(\delta - g')(\overline{T} - t)} & \text{for } 0 \leq t \leq \tau \\ N & \text{for } t > \tau, \end{cases}$$

$$(A1.5) \qquad x(t) = \begin{cases} N/p \cdot \left(e^{(\delta - g')(\overline{T} - t)} - 1\right) & \text{for } 0 \leq t \leq \tau \\ 0 \text{ for } t > \tau \end{cases}$$

The time path for S:

If $T \leq \tau$:

$$(A1.6) \qquad S(t) =$$

$$\frac{e^{g't}}{p} \left\{ pS_0 \left[1 - \frac{(1 - e^{-\delta t})}{(1 - e^{-\delta T})} \right] + N \int_0^T e^{-g't} dt \cdot \left[\frac{(1 - e^{-g't})}{(1 - e^{-g'T})} - \frac{(1 - e^{-\delta t})}{(1 - e^{-\delta T})} \right] \right\},$$

If $T > \tau$:

$$(A1.7) \qquad S(t) = \begin{cases} \dfrac{e^{g't}}{p} \left\{ pS_0 \left[1 - \dfrac{(1-e^{-\delta t})}{(1-e^{-\delta \overline{T}})} \right] + N \int_0^{\overline{T}} e^{-g't} dt \cdot \left[\dfrac{(1-e^{-g't})}{(1-e^{-g'\overline{T}})} - \dfrac{(1-e^{-\delta t})}{(1-e^{-\delta \overline{T}})} \right] \right\} \text{ for } t \leq \tau \\ 0 \quad \text{for } t \geq \tau \end{cases}$$

A2:

From $(A1.2)$, when $T \leq \tau$,

$$v = \int_0^T \ln \left[(N/\theta)\, e^{(\delta - g')(T-t)} \right] e^{-\delta t} dt = (\ln N - \ln \theta) \int_0^T e^{-\delta t} dt + (\delta - g') \int_0^T (T-t) e^{-\delta t} dt.$$

Integrating the last term by parts,

$$(A2.1) \qquad v = (\ln N - \ln \theta) \int_0^T e^{-\delta t} dt + h(T), \text{ where } h(T) \equiv \left(\tfrac{\delta - g'}{\delta} \right) \left(T - \int_0^T e^{-\delta t} dt \right).$$

Substituting this term into equation (7) yields:

$$(A2.2) \qquad V(T) = \frac{\ln N - \ln \theta}{\delta} + \frac{h(T) - z}{(1 - e^{-\delta T})}.$$

The derivative of this function with respect to T is

$$(A2.3) \qquad \frac{\partial V}{\partial T} = \frac{1}{\delta} \left[-\frac{1}{\theta} \frac{\partial \theta}{\partial T} + (\delta - g') - \frac{h(T) - z}{\int_0^T e^{-\delta t} dt \cdot \int_0^T e^{\delta t} dt} \right].$$

The derivative of the definition of θ in $A1$,

$$\frac{\partial \theta}{\partial T} = \frac{\left(1 - \theta e^{-\delta T}\right) \theta}{\int_0^T e^{-\delta t} dt} - \theta g', \text{ and } \frac{1}{\theta} \frac{\partial \theta}{\partial T} = \frac{1 - \theta e^{-\delta T}}{\int_0^T e^{-\delta t} dt} - g'.$$

Substituting this expression into $(A2.3)$ yields:

$$(A2.4) \qquad \frac{\partial V}{\partial T} = \frac{z - f(T)}{(1 - e^{-\delta T}) \cdot \int_0^T e^{\delta t} dt}, \text{ where } f(T) \equiv h(T) + (1 - \theta) \int_0^T e^{-\delta t} dt.$$

Using $(A1.4)$, when $T > \tau$:

$$v = \int_0^\tau \ln \left[N \cdot e^{(\delta - g')(\tau - t)} \right] e^{-\delta t} dt + \int_\tau^T \ln N \cdot e^{-\delta t} dt = \ln N \int_0^T e^{-\delta t} dt + \int_0^\tau \left[(\delta - g')(\tau - t) \right] e^{-\delta t} dt$$

Again integrating by parts and substituting into (7),

$$(A2.5) \qquad V = \frac{\ln N}{\delta} + \frac{h(\tau) - z}{(1 - e^{-\delta T})}.$$

Noting that T appears only in the denominator of this last term, the derivative of this function is

$$(A2.6) \qquad \frac{\partial V}{\partial T} = \frac{z - h(\tau)}{(1 - e^{-\delta T}) \cdot \int_0^T e^{\delta t} dt}.$$

Equation (8) in the text uses the definition of $\overline{T}$ to combine $(A2.2)$ and $(A2.5)$. Equation (9) in the text combines $(A2.4)$ and $(A2.6)$.using the definition of $\overline{T}$ and the fact that, since $\theta(\tau) \equiv 1$, $f(\tau) = h(\tau)$. The properties of $f(\overline{T})$:

When $T < \tau$, $\dfrac{\partial f}{\partial T} = \left[1 - \theta e^{-\delta T} - \dfrac{g'}{\delta}\left(1 - e^{-\delta T}\right)\right] - \dfrac{\partial \theta}{\partial T} \int_0^T e^{-\delta t} dt.$

Substituting again for $\partial\theta/\partial T$ and rearranging,

$\dfrac{\partial f}{\partial T} = \left[(1 - \dfrac{g'}{\delta})(1 - e^{-\delta T}) + (1 - \theta)e^{-\delta T}\right](1 - \theta) > 0$ (recall g' is strictly less than δ).

When $T \geq \tau$, $f(\tau) = h(\tau) = \left(\frac{\delta - g'}{\delta}\right)\left(\tau - \int_0^\tau e^{-\delta t} dt\right)$, which is not a function of T. So $\partial f/\partial T = 0$ for $T \geq \tau$.

References

Alston, L.J., G.D. Libecap, and R. Schneider (1995). "Property Rights and the Preconditions for Markets: The Case of the Amazon Frontier." *Journal of Institutional and Theoretical Economics* 15 (Mar):89 – 107.

Angelsen, A. (1995). "Shifting Cultivation and 'Deforestation': A Study from Indonesia". *World Development* 23 (10):1713 – 1729.

Barrett, S. (1991). "Optimal soil conservation and the reform of agricultural pricing policies," *Journal of Development Economics* 36(2): 167 – 187.

Batabyal, A.A. and D.M. Lee (2003). "Aspects of Land Use in Slash and Burn Agriculture", *Applied Economics Letters* 10: 821-824.

Batabyal, A.A. and H. Beladi, (2004). "Swidden Agriculture in Developing Countries", *Review of Development Economics* 8: 255-265.

Becker, G.S. and C. Mulligan (1997). "The Endogenous Determination of Time Preference." *Quarterly Journal of Economics*, (August): 729 – 758.

Boserup, E. (1965). *The Conditions of Agricultural Growth* (London: George Allen & Unwin Ltd.)

Bowes, M.D. and J.V. Krutilla (1985). "Multiple Use Management of Public Forestlands." in *Handbook of Natural Resource and Energy Economics*, vol. II, Kneese and Sweeney, Eds. (Elsevier Science Publishers B.V.)

Chiang, A.C. (1999). *Elements of Dynamic Optimization*, Waveland Pr Inc.

Clark, C. W. (1990). *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*, 2nd Ed. John Wiley & Sons, Inc.

Cropper, M. and C. Griffiths (1994). "The Interaction of Population Growth and Environment." *American Economic Review* 84(2): 250 – 254.

Dasgupta, G.S. and G.M. Heal (1979). *Economic Theory and Exhaustible Resources*. Cambridge Economic Handbooks. Cambridge University Press.

Dixit, A.K. (1990). *Optimization in Economic Theory*, 2nd Ed. Oxford University Press.

Food and Agriculture Organization (FAO) of the United Nations (2000). *Global Forest Resources Assessment* 2000, "Executive Summary".www.fao.org/DOCREP/004/Y1997E/ y1997e05.htm#bm05.

Fisher, Irving (1930). *The Theory of Interest* (New York: Macmillan).

Gillis, M., D.H. Perkins, M. Roemer and D.R. Snodgrass (1987). *Economics of Development*, Second Ed. W.W. Norton and Co. New York.

Grepperud, S. (1997). "Soil conservation as an investment in land," *Journal of Development Economics* 54: 455 – 467.

Hausman, J.A. (1979). "Individual Discount Rates and the Purchase and Utilization of Energy-using Durables." *Bell Journal of Economics* 10 (Spring): 33- 54.

Hirshleifer, J and J. G. Riley (1992). *The Analytics of Uncertainty and Information*. Cambridge Surveys of Economic Literature. Cambridge University Press.

Holden, S. T. and H. Binswanger (1998). "Small-Farmer Decisionmaking, Market Imperfections, and Natural Resource Management in Developing Countries," in *Agriculture and the Environment: Perspectives on Sustainable Rural Development*, Ernst Lutz, Ed. A World Bank Symposium, Oct. 1998, 50 – 70.

Holden, S. T., B. Shiferaw, and M. Wik (1998). "Poverty, Market Imperfections, and Time Preferences: Of Relevance for Environmental Policy?" *Environment and Development Economics* 3(1): 83 – 104.

Kurz, M., R.G. Spiegelman and R.W. West (1973). "The Experimental Horizon and the Rate of Time Preference for the Seattle and Denver Income Maintenance Experiments." Occasional paper. Stanford, Calif.: Stanford Research Institute.

Lawrence, E.C. (1991). "Poverty and the Rate of Time Preference: Evidence from Panel Data." *Journal of Political Economy* 99(1): 54 - 78.

Lewis, T. and R. Schmalensee (1979). "Non-convexity and optimal harvesting strategies for renewable resources," *Canadian Journal of Economics* 12(4): 677 – 691.

Lopez, R. (1994). "The Environment as a Factor of Production: The Effects of Economic Growth and Trade Liberalization," *Journal of Environmental Economics and Management* 27: 163-184.

Lopez, R. (1997). "Environmental externalities in traditional agriculture and the impact of trade liberalization: The case of Ghana," *Journal of Development Economics* 53(1): 17-39.

Mendelsohn, R. (1994). "Property Rights and Tropical Deforestation." *Oxford Economic Papers* 46: 750 - 56.

Pender, J. L. (1996). "Discount Rates and Credit Markets: Theory and Evidence from Rural India," *Journal of Development Economics* 50(2): 257 – 96.

Schneider, R., G. Platais, D. Rosenblath, and M. Webb (1993). "Sustainability, Yield Loss and Imediatismo: Choice of Technique at the Frontier." Washington, DC: The World Bank, Latin America Technical Department, Environment Division, Dissemination Note #1.

Shively, G. (2001). "Poverty, Consumption Risk, and Soil Conservation," *Journal of Development Economics* 65: 267 – 290.

Singh, I., L. Squire and J. Strauss (Eds.) *Agricultural Models. Extensions, Applications, and Policy* (Baltimore, MD: Johns Hopkins University Press).

Southgate, D., R. Sierra, and L. Brown (1991). "The Causes of Tropical Deforestation in Ecuador: A Statistical Analysis." *World Development* 19 (9): 1145 - 51.

World Commission on Environment and Development (1987). *Our Common Future.* (Oxford University Press)

World Bank (1992). *World Development Report: Development and the Environment.* (Oxford University Press)

World Bank (2003). *World Development Report: Sustainable Development in a Dynamic World.* (Oxford University Press)

World Resources Institute (WRI). 1996 - 97 *World Resources* (New York and Oxford: Oxford University Press).

Figure 1

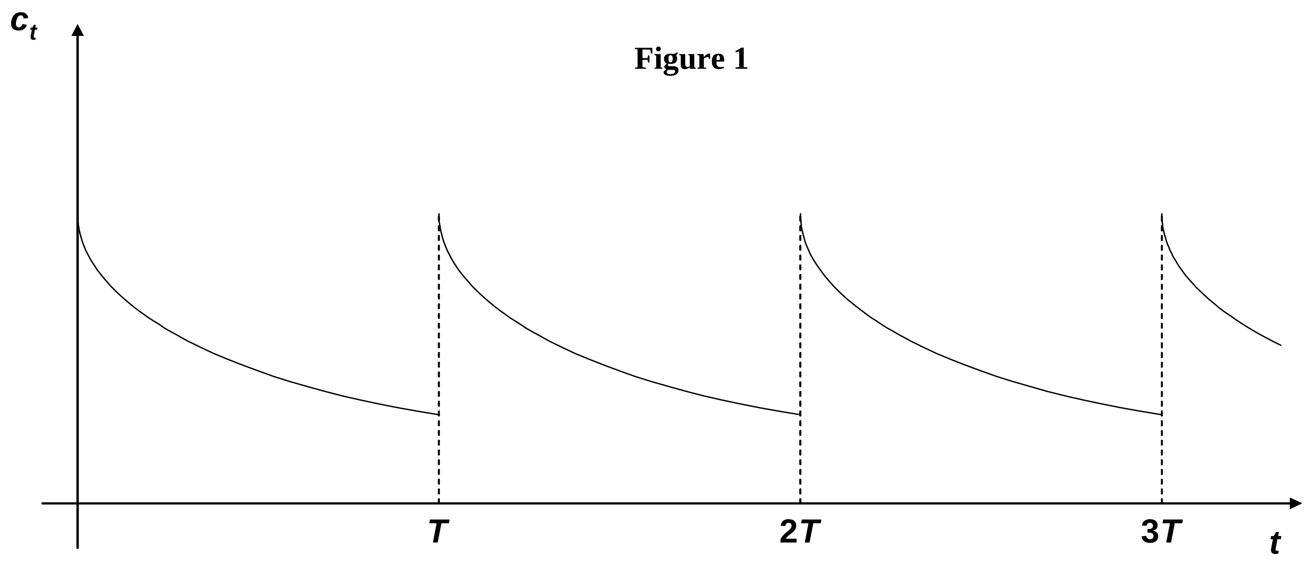


Figure 2

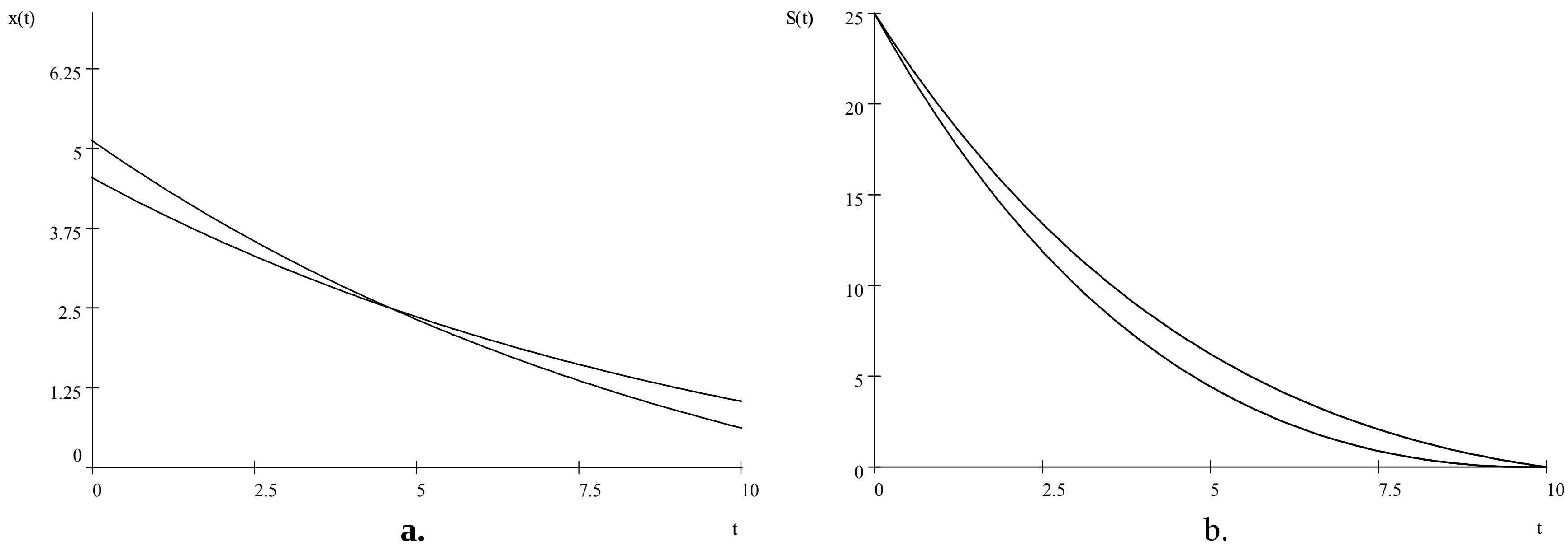


Figure 3

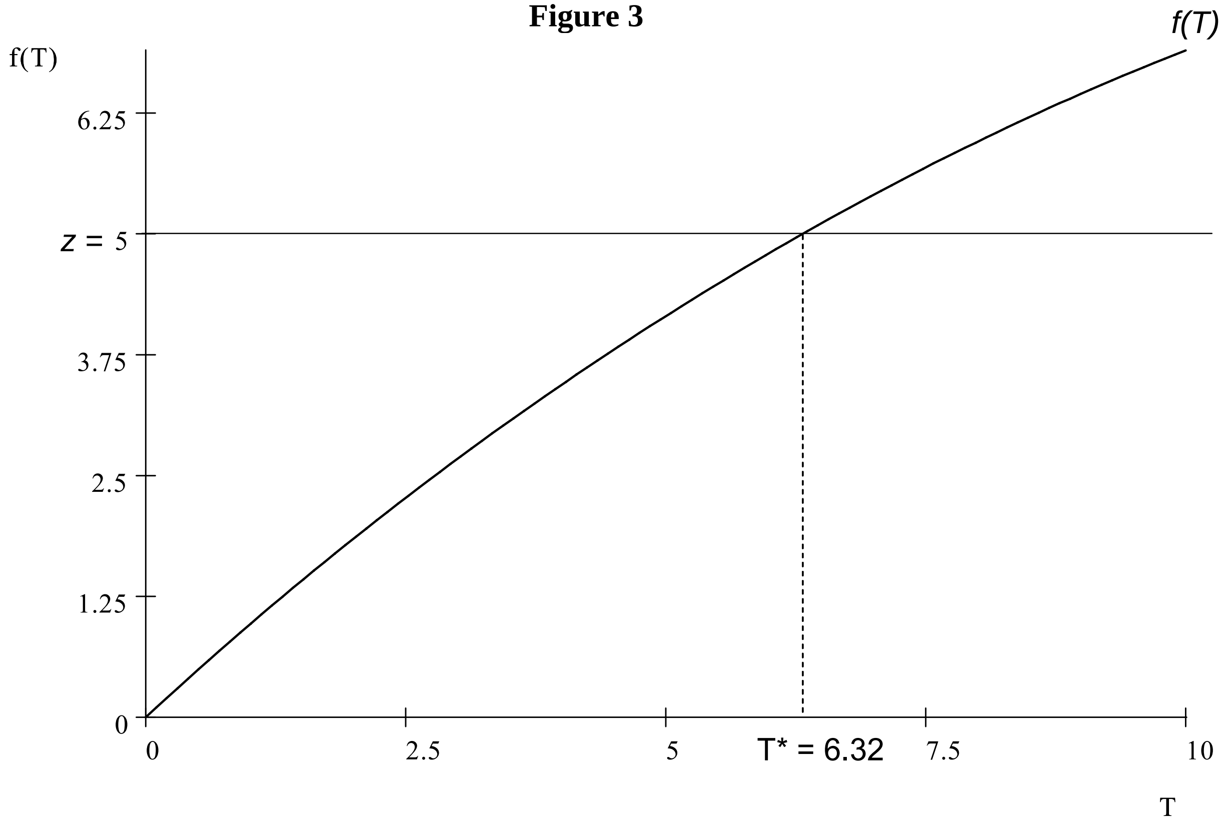


Figure 4

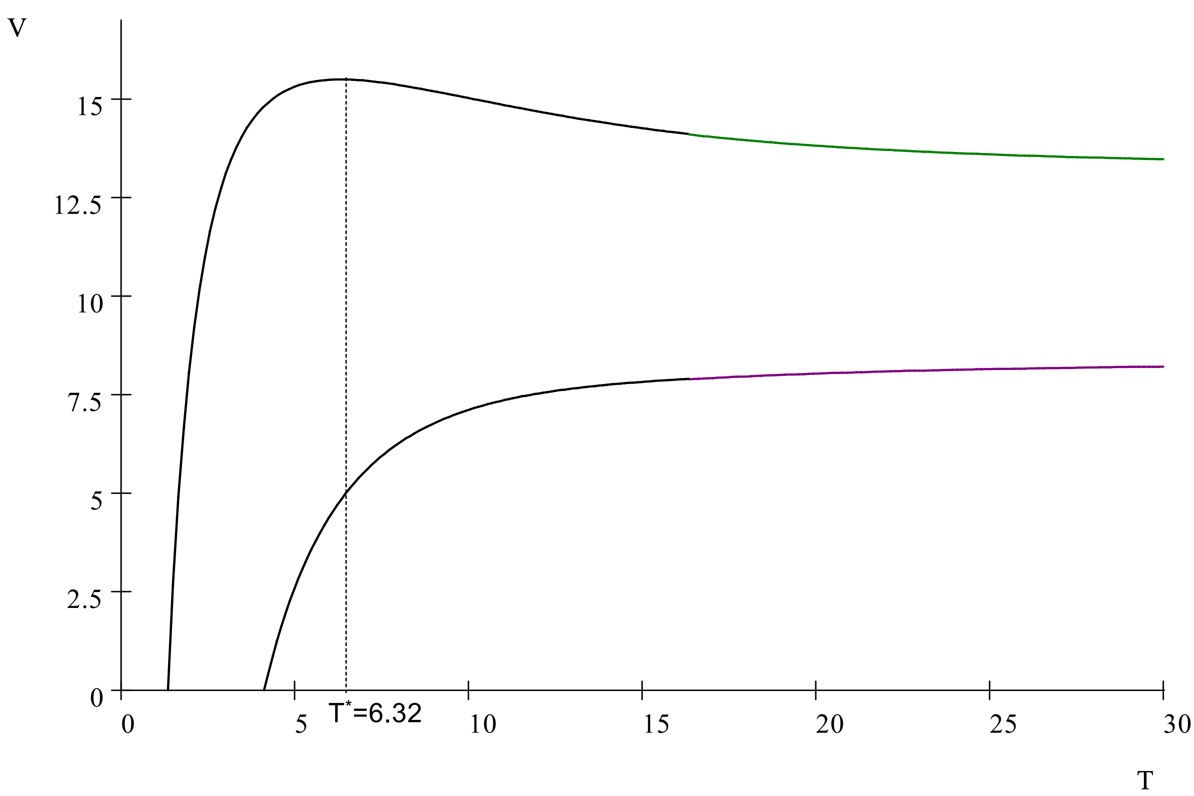
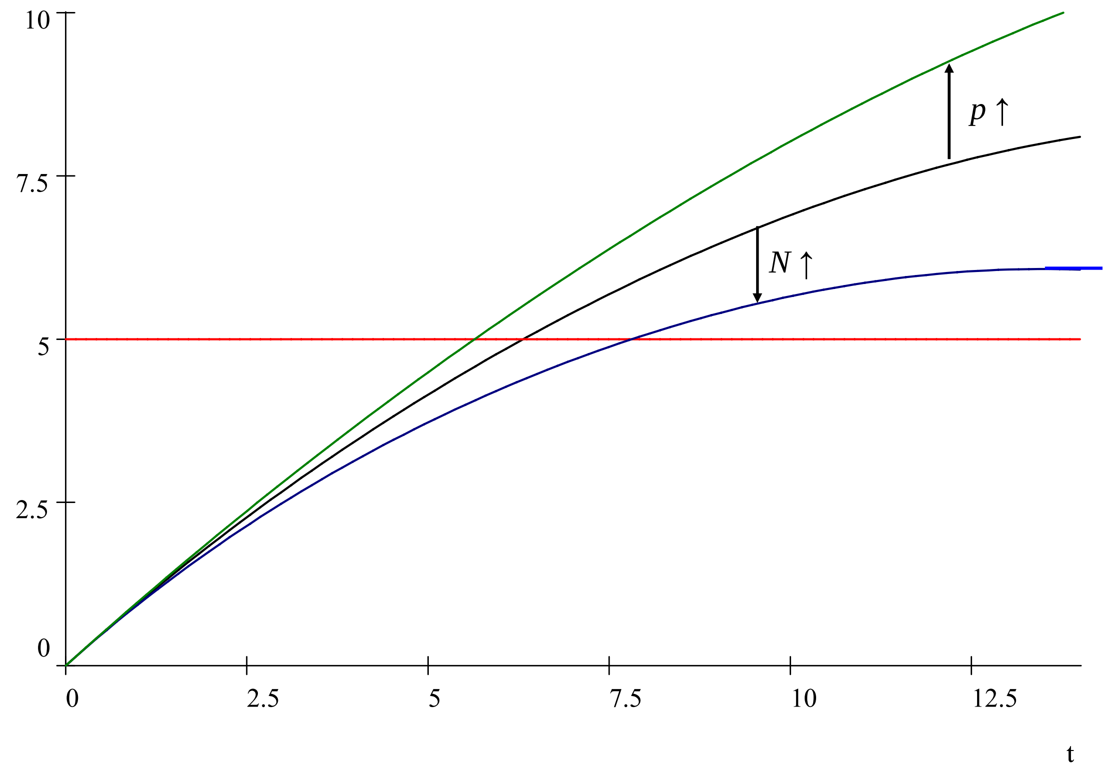


Figure 5



	Model *i*)	Model *ii*)	Model *iii*)
z	+	+	+
N	+	+	+
δ	–	+/–	–
p	–	–	–
S_0	–	–	–
i	NA	+	NA
r	NA	NA	–

Table 1