The Causes of Land Degradation along "Spontaneously" Expanding Agricultural Frontiers in the Third World

Douglas Southgate

The extent and consequences of deforestation and related environmental degradation in the developing world have become the subject of considerable debate and concern. There is disagreement about how rapidly tree-covered land near the equator is being cleared or otherwise disturbed. Likewise, tropical deforestation's impacts have proven difficult to identify and to evaluate. By contrast, the contribution small farmers make to deforestation is universally understood. Land clearing has been more rapid in Rondonia, for example, than anywhere else in the Brazilian Amazon and more than half the deforested land in that state is divided among small agricultural holdings (Browder 1988; Mahar 1989). Throughout the developing world, small farmers are primary agents of deforestation.

Small farmers migrate to the third world's forested hinterlands for several reasons. In Indonesia, Brazil, and elsewhere, many colonists have participated in settlement projects organized and directed by the public sector (Repetto and Gillis 1988). Most colonization, however, is "spontaneous," stimulated by a variety of push and pull factors. Blaikie (1985) argues that the pursuit of socially disruptive rural development strategies as well as land exhaustion cause small farmers to emigrate from areas they have long cultivated. In southern Brazil, they have been selling off their parcels, taking advantage of prices inflated by tax and other policies favorable to those with large land holdings (Binswanger 1989). Moving to agriculture's extensive margin is promoted by infrastructure development, which reduces the cost of marketing commodities grown in remote areas. Agricultural colonists in many countries also benefit from grace periods for development credit and other subsidies (Pearce and Myers 1988).

In addition to being induced to migrate to frontier areas, agricultural colonists in the third world face tenure regimes that promote deforestation. Quite often, removing trees and other vegetation is a prerequisite for establishing formal property rights. In Sudan, for example, the parastatal Mechanised Farming Corporation awards fifteen-year leases only to individuals who clear 85 percent of their holdings in three years. Alternatively, formal property law may make no mention of deforestation's being required for tenure. But since developing country governments usually take years to adjudicate claims for formal property rights---particularly claims made by small farmers settling in hinterlands---colonists tend to safeguard pending land rights by using their parcels continuously for crop or livestock production. In addition, agricultural use rights are the only form of land tenure available to private agents in many countries. The government of Ecuador, for example, terminated all private timber concessions in the country's "forest patrimony" in 1982. Agricultural colonization of tree-covered land is still permitted, however.

Although the factors causing small farmers to migrate to agriculture's extensive margin and to clear too much land are widely acknowledged, the cycle of excessive deforestation and erosive farming usually observed along third world agricultural frontiers has received scant attention in the literature. Focusing on the cycle emerging along "spontaneously" expanding frontiers, this paper's analysis addresses colonists' choices among resource development options with the aid of a model designed to reflect land tenure arrangements typically encountered in areas undergoing settlement. The model is used to assess the effectiveness of institutional and noninstitutional remedies of land degradation problems in developing country hinterlands undergoing "unplanned" settlement.

I. THE MODEL

Agricultural colonists in the third world cannot be expected to follow an efficient sequence of land clearing and land improvement, like that described by Hochman and Zilberman (1986). Where agricultural use rights are the salient feature of a tenure regime, settlers neglect rents associated with forestry and other non-agricultural land uses. Furthermore, most colonists realize that they risk losing land not in use for crop or livestock production to other settlers if they allow their actions to be influenced by the judgment that future deforestation is more profitable than present land clearing. Accordingly, any parcel is cleared immediately if agricultural rents can be captured by doing so.

The design of this paper's model describing agricultural colonists' choices among resource development options reflects the tenure regime facing that group. That is, it is based on the premise that settlers are obliged to neglect returns associated with non-agricultural land uses and to respond immediately to any opportunity to capture agricultural rents. This implies that a causal analysis need address only the intratemporal allocation of labor between erosion control and land clearing.

In general, the agricultural rents associated with land clearing and erosion control depend on the value of additional crop production associated with soil conservation, the value of crops and livestock produced on deforested land, and the opportunity cost of non-land inputs. The first two elements of agricultural rents are easy to model since commodity prices, which are determined in national or international markets, are not greatly influenced by crop and livestock production (or area planted to crops or pasture grasses) in the frontier region. Also, although it is not essential for the analysis, assuming that farmland never reverts to a non-agricultural use makes it easy to model rents captured by the frontier region's farmers. Finally, no major insights are lost by assuming that, because of their limited access to agricultural chemicals and credit, settlers possess only one non-land input: labor.[*1*] Of course, the opportunity cost associated with using that input either to clear land or to control erosion depends on the return to labor allocated to other activities.

Keeping in mind these assumptions, let us turn to a discussion of the three elements of agricultural rents small farmers capture in a frontier region. Next, that group's choices between land clearing and erosion control are described and interpreted.

The impacts on the present value of future crop production associated with erosion control measures now being put in place (i.e., being installed in period 0) can be represented with a single function, PVc. Because the net returns to soil conservation are higher on some farms than on others, there is an increasing and concave relationship between PVc and the total area receiving conservation practices, which is equal to labor currently allocated to erosion control, Nc, divided by the labor intensity of erosion control, c/hectare.

PVc = PVc(Nc/c),PV[']c>0 and PV["]c < 0. [1]

A single function, PVd, can also be used to describe the present value, at farm gate, of crops and livestock produced on land cleared in period 0. Since fertile or well situated parcels are cleared before less productive or remote parcels, PVd is an increasing and concave function of the extent of deforestation,[2] which can be expressed as labor currently allocated to deforestation, Nd, divided by the labor intensity of clearing, d/hectare.

PVd = PVd(Nd/d), PV[']d > 0 and PV["]d < 0. [2]

The opportunity costs of labor allocated to erosion control and deforestation do not depend only on Nc, Nd, and the intensity of farming in the frontier region. They are also a function of off-farm employment opportunities in the frontier region and the performance of other regions' labor markets. In this model, however, Nc and Nd are the only variables stated explicitly in the convex function, W, describing the scarcity value of labor. The first partial derivatives of W are positive.

We can normalize units of measurement in order to say that one unit of labor is needed to work a hectare where erosion is not controlled. Also, we can say that the application of such measures interrupts all farming activity for an entire year (or growing season). The opportunity cost of labor allocated to erosion control and land clearing during period 0, then, is:

W0 = W0[(1 - 1/.c)Nc + Nd]. [3]

Labor allocated in the future to crop and livestock production is affected both by the current extent of deforestation and by the area where conservation measures are now being applied. Given the assumption that agricultural land is never abandoned, the former employment impact equals Nd/d per annum. To address the latter impact, a coefficient, a, equal to a persisting difference between labor needed to work a hectare where erosion is not being controlled and labor used on a hectare where conservation measures are in place, is specified. Many farmers who practice conservation tillage, for instance, find that coefficient to be positive because they spend less time cultivating their fields. Alternatively, if an erosion control measure (e.g., a terrace) requires substantial maintenance, then the coefficient is negative. Given these definitions. a real discount rate, r, and future shadow prices of labor, W[']ts, the present value of future employment impacts of Nc and Nd is:

$$\underline{W} = \int_1^\infty W_t[N_d/d - (a)(N_c/c)]e^{-rt}\,dt. \qquad [4]$$

The elements of agricultural rents associated with Nc and Nd, equations [1] through [4], can be combined to form an objective function for the model describing efficient intratemporal allocation of settlers' labor:

PVc(Nc/c) + PVd(Nd/d) - W0[1 - 1/c)Nc + Nd] - W. [5]

If all potential upper and lower bounds on the optimal values of the choice variabies, N[*]c and N[*]d, are inactive, then the Kuhn-Tucker conditions are:

$$W'_o[(1 - 1/c)N^*_d + N^*_d]$$
$$= PV'_c/c + a/c \int_1^\infty W'_t e^{-rt}\, dt = R_c/c. \quad [6]$$

$$W'_o[(1 - 1/c)N^*_c + N^*_d]$$
$$= PV'_d/d - 1/d \int_1^\infty W'_t e^{-rt}\, dt = R_d/d. \quad [7]$$

Equations [6] and [7] indicate that a settler should increase labor allocated to erosion control or to deforestation up to the point where the current wage, W[1]0, equals the remaining arguments of marginal agricultural rents associated with Nc and Nd: Rc/c and Rd/d, respectively.

The difference between these guidelines and efficient trade-offs made under alternative tenurial environments is clearest in the case of efficient deforestation effort, N[*]d. Where all land is privately owned, for example, anyone wishing to clear a parcel for crop or livestock production must first compensate that parcel's owner. Compensation, which would enter negatively on the right-hand side of equation [7], would equal the parcel's agricultural rental value (Rd/d minus W[']0 in this model) or its non-agricultural rental value, whichever is greater. Where they are obliged to make such compensation, farmers push agriculture's extensive margin only up to where the two rental values are equal. By contrast, where farmers need not pay anyone before clearing a parcel, they will follow the allocational guideline stated in equation [7], setting N[*]d too high in order to push the extensive margin to where the agricultural rental value of land is zero.

As settlers, obliged to neglect all nonagricultural rents, allocate too much effort to land clearing, the current scarcity value of labor rises. In turn, the latter impact discourages erosion control. This linkage between Nc and Nd is illustrated by referring to a four quadrant diagram (Figure 1), the northeastern and southwestern quadrants of which show Rc/c and Rd/d, respectively. Also indicated in the southwestern quadrant is the difference between Rd/d and the marginal rental value of tree-covered land, C/d. The marginal opportunity cost of labor currently allocated to soil conservation and land clearing, W[1]0, is shown in the northwestern quadrant and the sum of N[*]c and N[*]d is represented in the southeastern quadrant. Note that, if the tenure regime were to change so that farmers could internalize the marginal rental value of tree-covered land, not only would labor allocated to deforestation decline, from N[*]d to N[*]d['], but the associated decrease in wages would induce an increase in conservation effort, from N[*]c to N[*]c['].

Of course, the degree to which tenurial conditions influence agricultural colonists' behavior depends on the elasticity of functions describing the components of agricultural rents. In addition, labor misallocation is great only if marginal non-agricultural rents, C, are large. Decisions made in Malaysia and other countries to arrest settlement in forested areas indicate that the net returns to tropical forest management are often greater than rents yielded by degraded cropland or pasture established where trees used to stand (Schmidt 1987).

II. FACTORS INFLUENCING DEFORESTATION AND SOIL CONSERVATION

The model presented in the preceding section yields insights into why a cycle of excessive deforestation and insufficient erosion control emerges in the vicinity of a spontaneously expanding agricultural frontier in the third world. It can also be used to demonstrate why, under a tenure regime that prevents settlers from capturing nonagricultural rents, changes in price signals and technology result in mixed environmental impacts. A detailed analysis of the effects of those changes on labor agricultural colonists allocate to land clearing and soil conservation appears in this paper's appendix. Some of the more important effects are discussed in this section.

Lower interest rates or higher commodity prices enhance both the present value of crops grown on deforested land and the present value of additional crop production associated with erosion control. These impacts are represented by outward displacement of the two functions, Rc/c and Rd/d, shown in the northeastern and southwestern quadrants, respectively, of Figure 1. Responding to this shift in incentives, settlers allocate more labor to soil conservation as well as to deforestation.[3] Alternatively, improved employment opportunities away from the agricultural frontier drive up the scarcity value of labor, W', which results in declines in both soil conservation and deforestation (Southgate and Pearce 1988).

General relationships exist between land clearing and soil conservation, on the one hand, and interest rates, agricultural commodity prices, and wages, on the other hand, regardless of the structure of property rights. That is, the tenure regime affects the degree but not the direction of adjustment in N[*]c and N[*]d caused by change in any of those three economic incentives.

By contrast, whether N[*]c and N[*]d rise or fall in response to a change in timber values depends entirely on the tenure regime. If non-agricultural rents (value C in the model) can be captured, an increase in those rents caused by higher timber values discourages land clearing. Consequently, the current opportunity cost of labor falls, causing Nc to rise. Under a frontier tenure regime, by contrast, settlers selling logs removed from land to be used for crop or livestock production treat timber values as a negative argument of land clearing costs. Consequently, an increase in those values enhances Rd/d, both absolutely and relative to Rc/c, which accelerates deforestation and discourages soil conservation (see Figure 2).[4]

Though they influence the behavior of agricultural colonists, changes in interest rates, agricultural commodity prices, wages, and timber values are felt throughout an economy.

Infrastructure development and the introduction of new technology, however, can be focused specifically on frontier areas.

Infrastructure development enhances the farm-gate value of crops grown in areas previously beyond agriculture's extensive margin. Responding to the positive agricultural rental value of open access land in newly accessible areas, colonists allocate more labor to land clearing. The Kuhn-Tucker conditions in this paper's model suggest that management of existing farmland is also affected by infrastructure development. As indicated in Figure 2. a higher Nd pulls up the current wage, W[']0, which in turn causes farmers to cut back Nc. Infrastructure development, then, accelerates the cycle of deforestation and erosive land use in frontier regions.

The purpose of technological innovation is usually precisely the opposite of the usual effects of infrastructure development. In particular, less erosive land uses and cultivation practices are often promoted in the hope that land degradation will be arrested.

Certainly, beneficial impacts result from farmers' adoption of these techniques. For example, an improvement in methods to reduce soil loss either enhances the productivity of existing farmland or diminishes the labor-intensity of erosion control. Either way, Rc/c rises, which causes an increase in Nc. Alternatively, disseminating knowledge about agroforestry and other less erosive uses for newly cleared land reduces environmental damage associated with the colonization of a given area of land.

However, use of this paper's model highlights the misconceptions about environmental impacts that can arise from a partial economic analysis of an individual erosion control technique or a soil conserving land use. For example, while it will induce an increase in Nc, a reduction in the labor intensity of erosion control (represented in the model by a decline in parameter c or a) might also diminish the current scarcity value of labor, W[']0. As inspection of equation [7] shows, Nd will rise if N[*]c [1 -1/c] falls.[*5*] By the same token, extending information on less erosive uses of newly cleared hinterlands is likely to result in an increase in Nd. If the new uses are more profitable than the old ones (and if they are not, they will be ignored by settlers), then Rd/d is increased, much as it is when chain saws and other improved equipment for land clearing are made available to settlers or when governments and logging companies turn a blind eye toward the occupation of recently abandoned logging sites by small farmers (Myers 1984). As the returns to land clearing increase, both absolutely and relative to Rc/c, the cycle of land clearing and exhaustive land use accelerates (Figure 2).

III. SUMMARY AND CONCLUSIONS

Bromley and Cernea's (1989) observation that an institutional crisis typically underlies a tangible environmental problem applies directly to the subject of this paper's analysis. Land degradation is severe in the vicinity of spontaneously expanding agricultural frontiers in the third world because of the tenure regimes facing agricultural colonists. Specifically, one's being able to acquire property rights in "idle" land by converting it to an agricultural use not only induces rational settlers to deforest excessively but also discourages them from conserving existing farmland.

This paper's analysis also indicates some potential limitations and pitfalls of remedying institutionally induced degradation of developing country hinterlands through non-institutional measures. For example, in addition to reducing soil loss, the introduction of less erosive farming techniques can accelerate deforestation just as extending information on less erosive uses of newly cleared hinterlands can result in additional agricultural colonization. Similarly, removing policy-induced distortions in markets for labor, credit, and agricultural commodities can either encourage soil conservation and land clearing or discourage both. At an extreme, a rise in timber prices can actually accelerate the cycle of deforestation and erosive farming, given tenurial conditions facing agricultural colonists.

Alone, then, technological innovation or price deregulation does not resolve the problem of land degradation along agricultural frontiers. The cycle of excessive land clearing and erosive farming can be broken only by accomplishing the politically charged task of changing the institutional causes of that cycle. To be specific, conservation of forested hinterlands is encouraged by strengthening the property rights of settlers, of those adversely affected by deforestation and erosion, or of both groups.

APPENDIX SENSITIVITY ANALYSIS OF KUHN-TUCKER CONDITIONS

How agricultural colonists' decisions regarding deforestation and erosion control are affected by price changes or the introduction of new agricultural technology can be determined through partial differentiation of the Kuhn-Tucker conditions, equations [6] and [7].

Because the partial derivative of either PV[']c or PV[']d with respect to some current or future commodity price, Pt, is positive, both [[partialdiff]](Rc/c)[[partialdiff]]Pt and [[partialdiff]](Rd/d)[[partialdiff]]Pt are likewise positive. By contrast, [[partialdiff]](W[']0)/[[partialdiff]]Pt is zero. Consequently, an increase in P, causes both N[*]c and N[*]d to rise.

In order for N[*]c to decline as the real discount rate, r, rises, [[partialdiff]][Rc/c]/[[partialdiff]]r must be negative. This is the case as long as

$$\partial(PV_c'/c)/\partial r < -\partial\left[a/c \int_1^{\infty} W_t' e^{-rt}\, dt\right]/\partial r$$

$$= ta/c \int_1^{\infty} W_t' e^{-rt}\, dt,$$

which holds as long as parameter a is not a large negative number (i.e., as long as current erosion control does not greatly increase the labor intensity of agricultural production in the future). This restriction on the value of parameter a is rarely binding. The first partial denvative, [[partialdiff]][Rd/d]/[[partialdiff]]r, is negative, indicating a decreasing relationship between r and N[*]d, as long as

$$\partial(PV'_d/d)/\partial r < -t/d \int_1^{\infty} W'_t e^{-rt}\, dt.$$

An increase in the opportunity cost of labor causes N[*]c to decline as long as the increase in the current scarcity value of labor, [[Delta]]W[']0, is greater than the change in Rc/c: a/c [[florin]][[[infinity]]]1 [[Delta]]W[']t e[-rt] dt. Similarly, because an increase in W['] diminishes Rd/d, there is a decreasing relationship between labor's scarcity value and N[*]d.

A reduction either in net clearing costs (e.g., because parameter d has declined) or in marketing costs will enhance Rd/d while having no impact on Rc/c. Because the former impact causes N[*]d to increase, the current marginal opportunity cost of labor, W'0[(1 - 1/c)N[*]c + N[*]d], rises, which results in a reduction in N[*]c.

Similarly, a reduction in parameter c (i.e., the labor intensity of erosion control) diminishes Rc/c while having no effect on Rd/d. However, N[*]d can rise along with N[*]c as W'0 falls. Let N[*]c and c represent initial values and [[Delta]]N[*]c and [[Delta]]c represent positive and negative change from initial values. N[*]d will increase if:

$$(1 - 1/\underline{c})\underline{N}^*_c > (1 - 1/[\underline{c} + \Delta c])(\underline{N}^*_c + \Delta N^*_c)$$

$$\Delta N^*_c < \underline{N}^*_c/[\underline{c} + \Delta c] - \underline{N}^*_c/\underline{c} + \Delta N^*_c/[\underline{c} + \Delta c].$$

The first right-hand side term represents labor that would be diverted away from agricultural production if parameter c fell but N[*]c stayed the same. It is, by definition, larger than the second right-hand side term, which equals labor not used to produce crops and livestock given the original values of N[*]c and c. The reduction in farming effort associated with the increase in N[*]c is represented by the third term. If the latter reduction plus the positive difference between the first two terms exceeds [[Delta]]N[*]c, then W[']0 will fall, causing N[*]d to rise.

Southgate is associate professor, Agricultural Economics Department, Ohio State University, Columbus.

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1 Many agricultural colonists, of course, are not deprived of all non-land inputs save their own labor. Binswanger (1989) points out, for example, that the farmers who sell their holdings in southern Brazil before moving to the Amazon Basin have considerable financial resources. This fact does not alter the validity of this paper's analysis, however, since the opportunity costs of an "input bundle'" would have the same properties as the opportunity costs of labor or any other single input.

2 Alternative forms of the two functions, PV, and PVd, are described explicitly in Southgate and Pearce (1987).

3 At least as important as a general increase in crop and livestock prices, of course, is a change in relative prices. Also, colonists' expectation that commodity prices will increase at some future date might induce them to deforest more land now, even when current prices might not be high enough to justify such action. This might explain, in part, the speculative clearing of land (undertaken to secure property rights) in some parts of Brazil (Mahar 1989).

4 That timber sales are an important element of rents where private agents can only acquire agricultural use rights has been demonstrated in Ecuador. The prohibition, in 1981, of private timber concessions greatly encouraged agricultural colonists in the northwestern part of that country to extract and to sell commercial timber rather than to burn that resource while clearing land. In 1981, Ecuador imported a little less than $1.4 million worth of chainsaws. By 1985, three years after concessions were terminated, imports had risen to $4.7 million, primarily so that colonists' demand for chainsaws (which are an essential input for timber extraction) could be met (Montenegro and Dunni 1989). A forestry expert working for the U.S. Agency for International Development indicates that revenues from timber sales exceed clearing costs for many agricultural colonists in northwestern Ecuador (Cannon 1989).

5 This latter possibility deserves serious attention inasmuch as North American farmers practice reduced tillage primarily to contain labor costs and not so much to arrest soil loss. If farmers in the developing world behave likewise, then some labor will be redirected to land clearing.

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