Poverty Traps and Resource Dynamics In Smallholder Agrarian Systems

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Abstract: Poverty traps and resource degradation in the rural tropics appear to have multiple and complex, but similar, causes. Market imperfections, imperfect learning, bounded rationality, spillovers, coordination failures and economically dysfunctional institutions all play a role, to varying degrees in different places and times. Pinning down these mechanisms empirically remains a challenge, however, but one essential to the design of appropriate interventions for reducing poverty and environmental degradation in areas where livelihoods depend heavily on natural resources.

Key words: development, feedback effects, multiple equilibria, resilience, stability

Introduction

The words "ecology" and "economics" originate from the same Greek root, *oikos*, meaning "household" or "estate", with "eco-logy" concerned with study of, and "eco-nomics" with management of the complex aggregate. This common etymological root suggests deep connections between the two disciplines.

Take, for example, the burgeoning literatures in each discipline on thresholds and multiple dynamic equilibria, often referred to as "stable states". In this context, multiple equilibria refers to the situation in which different initial conditions lead to qualitatively different equilibrium paths converging on different steady states.[1] Systems characterized by multiple equilibria are locally stable (or "resilient") in the neighborhood of attractors (or "stable equilibria") but prone to sudden shifts in their dynamics at critical thresholds (or "tipping points" or "unstable equilibria"). Such systems pique the interest of scholars in both disciplines. At least since the seminal work of Holling (1973), May (1977) and Hanski et al. (1995),[2] environmental scientists have worked tirelessly at identifying and understanding thresholds in ecological systems in order that they might help resource managers avoid catastrophic collapse of key ecosystems. Economists' interest focuses more on the reverse process, on understanding why some people, communities and even entire nations remain mired in grinding poverty while others have enjoyed rapid improvements in standards of living, i.e., how to move social systems from low- to high-level equilibria.

The obvious latent connections between these lines of inquiry are too often overlooked, to the detriment of each discipline. Conservationists too often ignore the predictable consequences of human agency; people adapt behaviors in response to changes in environmental management, often generating unintended consequences. Similarly, those of us studying the economics of poverty are only just beginning to grasp the importance of understanding the dynamics of agroecosystems on which many livelihoods and technologies depend, and the

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feedback between the human and natural processes, especially in smallholder agrarian systems.

This paper reflects my current thinking on these issues, approached from the perspective of the economics literature on poverty traps. The next section defines a "poverty trap" and explores the general mechanisms by which such phenomena might originate. The subsequent section relates the possibility of poverty traps back to the underlying state of renewable natural resources (forests, soils, water and wildlife) in rural areas, explaining how multiple stable states can arise and prove mutually reinforcing with respect to both economic and ecological variables (e.g., pastoralist wealth and range conditions, smallholder incomes and land quality). Drawing on empirical examples from smallholder agrarian systems I know well in sub-Saharan Africa, I then describe how multivariate multiple equilibria emerge naturally from material and informational feedback between natural and socioeconomic systems, feedback that predictably switches between balancing processes that maintain system stability and reinforcing processes that lead to locally exponential growth or decay. The final brief section draws out some of the policy implications that follow from the connection between poverty traps and resource dynamics in the rural tropics. While degradation and persistent poverty are not inevitable, it seems equally true that closely coupled ecological, economic and humanitarian challenges will not be resolved of their own accord over time. Models that integrate the dynamics of human well-being and resource allocation with the underlying dynamics of natural systems have great promise for helping analysts and policymakers think through the relative merits and risks of alternative courses of action.

The Economics of Poverty Traps

The economics literature encompasses a range of definitions of a "poverty trap". The basic idea, per Azariadis and Stachurski (2004, p. 33), is that a poverty trap is "any self-reinforcing mechanism which causes poverty to persist". This can include single equilibrium systems where the unique equilibrium is at a low-level of well-being. But the more interesting cases of poverty traps emerge in the presence of multiple dynamic equilibria. Let us briefly consider what this means, somewhat more precisely, and how such phenomena might originate.

Assume some scalar measure of well-being that evolves over time, w_t – think of it as income, although the formulation is more general than that – that is generated by the stock of productive assets at the agent's disposal at the beginning of the period, a_t, a set of $m=1,\ldots M$ possible mappings of stocks into flows, $f^m(\cdot)$ – these could be production technologies, dividend or interest rates on financial assets, or terms of trade in market exchange –and an additive, mean-zero exogenous stochastic component (e.g., yield or price shocks) that reflects deviations of realized flows from their expected values, ε_t^m. The simple static view of an individual's livelihood choice, assuming expected utility maximization, is then

$$\underset{m}{Max}\, w_t^e \equiv f^m(a_t) \qquad (1)$$

where the agent chooses the means of using the assets at her disposal that yields the maximum expected flow of well-being, w^e, given the costs and benefits of each of the M livelihood mappings available to her. Call the resulting choice f^{m*}. Realized well-being for the period is subject to stochastic shocks, yielding

$$w_t \equiv f^{m*}(a_t) + \varepsilon_t^m \qquad (2)$$

This simple formulation allows for the existence of multiple production technologies, marketing channels or other means of mapping assets into flows of well-being. If $f^m(\cdot)$ follows the usual monotonicity, (weak) concavity and regularity (i.e., $f^m(0)=0$) conditions for each mapping, then initial asset holdings may effectively limit choice among alternative livelihoods unless complete and competitive financial markets exist, in which case the livelihood mappings are identical for all agents and no one's livelihood choice would be constrained by initial asset endowments, a_0, as one could freely borrow and then repay the loan at a parametric interest rate. However, given the pervasiveness of financial market imperfections in the developing world, livelihood choices typically are constrained by agents' asset endowments.

The possibility of financial contracts raises the issue of the dynamics inherent to the agent's choices. Assume that the asset stock follows a stochastic difference equation,

$$a_{t+1} = g^m(a_t, s_t, \varphi_t^m) \tag{3}$$

that one might reasonably expect to vary according to livelihood choice, where s_t is the chosen savings rate, and φ_t^m captures asset risk that may or may not be correlated with the income risk, ε_t^m, and might follow different distributions according to one's livelihood choice. Of course, the choice problem in equation (1) must now be adapted to value the stream of period-specific well-being measures and one must add the choice of s to the choice of m; but these are straightforward extensions.

The standard form in the economics literature for this growth function is to assume away asset risk and to assume constant depreciation, δ, and a unique law of motion (typically, to assume a unique asset and a unique livelihood/technology option). This simplifies (3) by assuming it follows a simple first-order difference equation:

$$a_{t+1} = s_t w_t + (1-\delta) a_t \tag{4}$$

The assumptions necessary to achieve these simplified dynamics – no allowance for different livelihoods governed by different underlying laws of motion, no prospective nonlinearities in those laws of motion, no asset risk – are rather burdensome if we want to understand patterns of behavior and natural resource dynamics in the rural tropics.

When M=1, the model with law of motion (4) reduces to the canonical, convex Ramsey-Cass-Koopmans neoclassical growth model and global convergence to a unique long-run steady state asset stock and level of well-being result. If that level of well-being falls below some relevant poverty line, $\underline{w}$, then the intertemporally separable dynamic programming problem described above defines a simple model of a poverty trap for *all* households. However, overwhelming empirical evidence concludes that (i) much of the world has not converged and is not converging on a low-level equilibrium, so that simple poverty trap model seems terribly unrealistic, and (ii) income convergence does not accurately describe economic growth at the macro level of nation states, which reflect instead 'divergence, big time' (Pritchett 1997). The empirical microeconomic evidence remains much less clear on this latter question. An emerging literature tries to explain this pattern.

As Carter and Barrett (2006) explain, one can account for divergent welfare paths through either or both of two alternative explanations. The first is the idea of conditional or club convergence, meaning that groups of individuals who share similar intrinsic characteristics tend to follow an equilibrium path and converge to a living standard and asset stock that are unique to their group or club. While there is convergence within clubs, there can be divergence between clubs. One or more clubs might converge on a unique, low-level equilibrium while one or more others converge on a unique, high-level equilibrium, thereby generating divergence with some persistent poverty. The second alternative posits thresholds and multiple equilibria for each individual, in this case distinct equilibria based on one's initial conditions, not group membership. This approach is quite similar to those found in the ecological literature on multiple stable states and system resilience. From this perspective, there is no unique dynamic equilibrium. Instead, controlling for one's immutable characteristics (that sort individuals into groups), both high and low level equilibria exist, with the path dynamics of the system conditional on the ex ante level of the state variable(s), i.e., the law of motion of a_t, described by equation (3), must be highly non-linear[3], perhaps even discontinuous at some threshold value.

This latter alternative, of threshold-based poverty traps, is inherently more interesting – as well as more promising – for the study of persistent poverty and renewable resource degradation in smallholder agrarian systems. At a low-level equilibrium, agents have no incentive, given the constraints they face, to invest in further asset accumulation, yet the low-level steady state, $\tilde{a}_i^{\ell}$, yields expected well-being below the poverty line, $w^e<\underline{w}$. There nonetheless exists some larger asset stock at which accumulation becomes attractive, leading to a higher-level steady state, $\tilde{a}^h$, and a higher corresponding expected level of well-being, $w^e>\underline{w}$. Asset accumulation thus becomes the engine of growth towards a stable, long-run steady state.[4] If a is a vector that includes natural assets such as forests, soils, water or wildlife, then the coupling of poverty traps and resource degradation becomes obvious and direct.

How might such multiple steady states systems emerge? The following subsections enumerate three distinct classes of explanations, any or all of which may apply in a given setting. Each carries slightly different implications for policy, which should serve as a caution against making facile prescriptions in the absence of detailed, empirical investigation of the etiology of an apparent poverty trap. But before we sketch out these differences, a couple of common characteristics apply to each explanation and thus bear comment. First, there must exist some mechanism(s) that introduce(s) nonconvexities into the envelope of $f^m(\cdot)$ mappings from equation (1) and, in particular, to the law of motion governing the asset stock, as reflected in equation (3). Intuitively, the marginal returns to accumulation must be (locally) *non-increasing* in the neighborhood of stable equilibria but must also be (locally) *increasing* somewhere between the two, at an unstable dynamic equilibrium, the threshold point at which the asset path dynamics bifurcate. Second, there must be some exclusionary mechanism(s) that prevent(s) individuals from simply choosing to surmount the threshold that divides basins of attraction to different stable equilibria. Otherwise, no one would continuously choose a low-level equilibrium path. The result of these two basic properties of threshold-based poverty traps is that (i) initial conditions matter,[5] and (ii) transitory shocks can have persistent effects, i.e., the system can be perturbed from one stable equilibrium to another by a single event.

Market imperfections

Development economics as a subdiscipline has focused heavily on the sources and consequences of market imperfections that generate inefficiency and retard asset accumulation and productivity growth. Such imperfections are the perhaps most obvious candidate explanation for the existence of threshold-based poverty traps.

Several variants of the market imperfections explanation exist. One holds that input (output) prices or transactions costs are negatively (positively) related to scale over some significant range, with those nonlinear terms of trade generating non-convexities in the envelope of $f^m(\cdot)$ mappings. For example, a small farmer with one or two cows might receive a lower price per liter for milk sold to a trader who incurs costs to reach him than would an identically located farmer with a large herd and much more milk to offer. As a consequence, the returns to investing in a second cow would be less than the returns to adding a cow to a large herd. If the cost of a cow falls between these two returns, there will exist multiple equilibrium herd sizes, each corresponding to a distinct level of expected well-being for the farmer. An economy in which the terms of trade one faces are endogenously determined by one's asset stock and investment decisions clearly suffers a market imperfection that will lead to violation of the fundamental welfare theorems.

A second variant is associated with analytically similar internal economies of scale, for example those that would arise from sunk costs associated with choosing higher-return livelihoods. In the strict internal economies of scale case, fixed costs become a nonlinear function of the asset stock. In the sunk costs case, the costs associated with each possible livelihood choice become time-varying, with higher initial (and irreversible) costs when one first chooses the corresponding livelihood. These create a friction that can lead to locally increasing returns at thresholds where agents rationally switch between alternative livelihoods (i.e., switch their choice of the optimal m). As Carter and Barrett (2006, pp. 188-9) note,

> "there are plentiful empirical examples of such patterns, for example, households possessing more assets who adopt higher-return crop varieties or agronomic practices, wealthier households who get skilled salaried employment rather than unskilled casual wage labor, or households who graduate from poultry or small ruminants to indigenous cattle to improved dairy cattle and advanced animal husbandry practices (for example, artificial insemination, supplemental feeding, and so forth) as wealth grows and these methods become affordable."

The same pattern then emerges as under endogenous terms of trade: there can exist multiple equilibrium asset holdings associated with different levels of well-being (and in this case different choices of m).

In each of these two cases, a second, implicit market imperfection – a credit constraint (more generally a financial liquidity constraint) – is necessary in order for anyone to remain in the low level equilibrium. If people could freely borrow at an interest rate less than the proportional improvement in the expected terms of trade that result from asset accumulation, anyone initially in the neighborhood of the low level equilibrium would rationally borrow the resources necessary to move to the high level equilibrium and then repay the loan. However, because credit constrained equilibria exist for a variety of reasons (Besley 1995), the threshold-based poverty trap can ensnare those with relatively unfavorable initial endowments and cause intergenerational transmission of poverty through failure to invest in education (Loury 1981) or induced child labor (Basu and Van 1998). Returning to the simple model of the preceding section, under the assumptions that there exists some mapping that generates non-negative well-being and that no borrowing is permitted, then no livelihood option for which the required costs exceed the asset stock will be chosen, regardless of how great the marginal returns to that activity might be. Suddenly initial conditions become fundamental to determining livelihood choice and the resulting accumulation and well-being dynamics.

Credit constraints are not the only financial market imperfection that might generate multiple equilibria. Uninsured risk may similarly cause some lower wealth households to allocate their assets so as to reduce risk exposure, trading off expected gains for lower risk, thereby making expected marginal returns to wealth lower for lower wealth households who are more risk averse than for those with greater ex ante endowments that either better enable them to self-insure or make them less risk averse (Bardhan et al. 2000, Carter and Barrett 2006). The result will be lower equilibrium asset holdings and levels of well-being for the initially poor.

One especially important form of response to uninsured risk relates to fertility decisions. As child mortality risk and the risk of unsupported adult disability fall, so do fertility rates. Beyond the obvious nonmaterial benefits they confer, children offer a source of labor and future financial support in economies where the elderly or inform otherwise lack ready access to the finance to support themselves or to hire workers. But because human population growth also means increased subdivision of other assets, such as land and livestock, endogenous human population growth can be another process that reinforces a poverty trap mechanism.

A final, and quite intuitive, poverty trap mechanism due to market imperfections arises from employers' inability to observe labor effort and productivity accurately and the resulting impact on wage determination. As Dasgupta and Ray (1986, 1987) and Dasgupta (1993) explain, asymmetric information in the labor market can lead naturally to a nutritional efficiency wage and resulting involuntary unemployment coupled with undernutrition. The result is an especially pernicious form of a poverty trap caused by physical impairment and thus reduced productivity.

These explanations of poverty traps based on market imperfections, liquidity constraints and resulting asset thresholds underpin much of the current policy discourse about poverty traps, perhaps best embodied by Sachs (2005). The gist of the Sachsian argument is that poverty traps can be overcome if only the world will provide adequate resources to overcome the market imperfections that presently obstruct capital accumulation and technology adoption in the poorest areas of the tropics. But this is not the only way to understand the origins of poverty traps.

Imperfect learning and bounded rationality

In spite of the plethora of models of imperfect information in development economics and cognate subdisciplines, assumptions of complete information and perfect rationality pervade the economics literature on economic growth. But in a complex environment characterized by highly nonlinear dynamics, it may be somewhat far-fetched to assume that agents have an accurate, even an unbiased sense of the likely effects of discrete behavioral changes. Those who have only ever been poor may have a hard time anticipating the changes associated with decisions associated with transitions well beyond the equilibrium with which they are familiar. Furthermore, agents may have a difficult time observing changes in the environment around them, especially changes occurring at some distance from their current position. In the notation above, individual actors may observe $f^m(\cdot)$ or the law of motion describing the state variable(s), a_t, with persistent error and thus make allocation errors – in livelihood choice and/or savings behaviors – as a result. Differences among agents in beliefs or subjective expectations can thereby generate what Mookherjee and Ray (2000) term "inertial self-reinforcement".

There are at least three distinct variants of this problem. First, there may be important informational lags such that some people cannot accurately observe current conditions, which only become apparent after a delay, by which time response may be prohibitively costly although early response would have been remunerative. An example might be the population state of a disease vector (e.g., mosquitoes) that is difficult to observe in the early, larvae stage but, if observed accurately, relatively easy to eradicate through larval management, yet is easy to observe but difficult to control once the population matures. Soil quality conditions typically inferred from stochastic yields that are also affected by rainfall and other environmental determinants may likewise evolve with only lagged, imperfect observation by farmers, causing them to miss windows of opportunity for sustaining fertility levels. Similarly, individuals may become aware of new production technologies or marketing channels with different lags, with those slower to learn about new opportunities facing reduced returns to adoption – following the classic "technology treadmill" argument (Cochrane 1958) – and hence diminished incentives to innovate. Informational lags can thus readily lead to multiple equilibria.

Second, there may be barriers or lags to learning that result from the differentiated nature of the social networks through which information flows imperfectly through a population. People may learn about jobs, emerging market opportunities, or improved technologies only if they are well-connected, or the speed with which they learn about such opportunities may affect the payoff from uptake. If there is an associational propensity among similar individuals – the poor network mainly with other poor people, and the rich with the rich – then multiple equilibria can result naturally from either signaling or learning effects (Montgomery 1991, Calvó-Armengol and Jackson 2004). Such models have not been widely adapted to the poverty traps context yet, but their applicability – to questions of technology adoption, market participation, finding remunerative employment, etc. – are rather intuitive (Durlauf 2002, Barrett 2005). If social networks are exogenously determined (e.g., by immutable factors such as race or gender), then this becomes a form of club convergence.

Finally, as Azariadis and Stachurski (2004, p.37) discuss, "in a boundedly rational environment with limited information, outcomes will be driven by norms, institutions and conventions. … however, norms, institutions and conventions are path dependent by definition. … [Therefore,] economies that start out in bad equilibria may find it difficult to break free." If people derive nonmaterial value from their relationships, the quality of which depends in part on social proximity and similar behaviors, then there may be strong, if subtle, pressures to conform to traditional local practices, discouraging innovation, which may be regarded as deviancy (Barrett 2005, Moser and Barrett 2006). Here again, the long-term effects of human population dynamics associated with social customs concerning marriage and fertility can have extremely important effects that could perhaps be avoided if human behaviors were less boundedly rational.

The implications of the imperfect learning, information-limited and bounded rationality models of poverty traps deviate substantially from those of the market imperfections explanations. In an informationally limited world, additional resources need not generate the most productivity-enhancing investments. Rather, the highest return interventions would be to provide more timely, accurate and universally available information so as to surmount barriers to learning and innovation.

Spillovers, coordination failures and economically dysfunctional institutions

This latter point about norms and conventions provides a natural segue to the third category of explanations for poverty traps. Relationships with others matter, and not just because they convey information on which one can act. There may be technological externalities operating through physical spillover effects, as when one farmer's failure to control pests leads to harvest losses on a neighbor's land and thereby depresses the returns to adopting higher-return crops or higher-yielding varieties. Or there may exist pecuniary externalities caused by induced price effects, as in the case of external economies of scale (Murphy, Schleifer and Vishny 1989). As is well known, such conditions generally preclude attaining even constrained Pareto optima (Greenwald and Stiglitz 1986). These spillover effects not only generate inefficiency, however, they can also lead to multiple stable equilibria. Bowles et al. (2006) describe a range of such cases that lead to poverty traps.

Such spillover effects are special cases of coordination failures, which result whenever externalities affect not only the welfare of others, but also their behaviors. Keeping with the earlier notation, now the livelihood mapping takes additional arguments, taking the general form $f^m(a, \hat{a}, \hat{m},)$ where $\hat{a}$ represents other agents' asset stocks and $\hat{m}$ reflects others' livelihood choices, each of which might now affect the returns to i's decisions. Game theory is replete with examples of coordination failures, in which there exist Pareto inferior equilibria, and often multiple equilibria depending on the rules of play.[6]

Coordination failures can all too easily become institutionalized through formal or informal rules that then guide individual and group behavior. Economically dysfunctional institutions at any of several levels of social aggregation can undermine incentives to accumulate assets or to invest in productivity improvements and, by so doing, perversely reinforce the economic dysfunctionality of the system (Barrett and Swallow 2006, Bowles et al. 2006).[7] Through corruption, weak property rights, limited contribution to public goods that are complementary inputs to private goods in production processes, etc., the institutions that define societies can both cause low investment and incomes and be caused by those conditions (North 1990, Bowles et al. 2006). A burgeoning literature traces historical paths of institutional development and links these patterns to subsequent economic performance, even centuries later (Engerman and Sokoloff 1997, Acemoglu et al. 2001).

Weak property rights are of special concern. If the security of one's assets is in question, incentives to invest are obviously sharply attenuated. And if assets are scarce because of limited investment, competition for them may become intense, reinforcing the insecurity that causes the scarcity in a reinforcing feedback loop. Some have gone so far as to claim that weak property rights is the fundamental obstacle to development in poor countries, explaining why the poor remain poor and the rich grow richer, i.e., why poverty traps appear (De Soto 1989, 2000, Acemoglu et al. 2002).

The coordination failures and economically dysfunctional institutions explanations for poverty traps point to still a different set of policy conclusions than those that follow from the preceding two classes of explanations. The problem now becomes one of appropriate mechanism design, of crafting rules of interaction – and rules for transitioning to those new rules – that will facilitate coordination, create focal points at Pareto dominant equilibria, and discourage venal behaviors that undermine individual incentives to cooperate and accumulate.

The Poverty Trap - Resource Dynamics Link

The preceding general discussion of the economics of poverty traps foreshadows a range of interlinkages between resource dynamics – and multiple stable states in environmental variables – and multiple socio-economic equilibria. In spite of some notable efforts in this direction (e.g., Dasgupta 1993, Berkes and Folke 1998, Shepherd and Soule 1998, van Kooten and Bulte 2000), these links remain relatively underdeveloped in the literature, not only conceptually (e.g., within the realm of formal theorizing), but especially empirically. We know surprisingly little empirical detail about the nature of feedback between closely coupled human and natural systems in the rural tropics. In this section I sketch out the key connections before offering some examples in section 4.

The Poor's Assets

The most fundamental connection between the dynamics of natural systems and human well-being in the rural tropics arises due to smallholders' heavy dependence on biophysical assets for their livelihoods. When the key state variables of two systems are shared in common, strong interdependence follows automatically. The question becomes the nature of the interrelationship(s) and the ranges over which balancing or reinforcing feedback effects dominate within and between systems.

In the course of long-term economic development, populations typically generate income from biophysical processes associated with crop and livestock agriculture, fisheries, forestry and hunting, saving some of the proceeds to reinvest these in a wide range of manufactured assets (e.g., buildings, financial instruments, machinery, physical infrastructure) and in skills embodied in human capital. The portfolio of human wealth thus evolves steadily, diversifying out of natural assets into manufactured wealth. In this stylized process, nature is a source of riches that facilitates improvement in the human condition, albeit often through unsustainable resource use patterns. Resource dependence plainly need not lead inexorably to a poverty trap; indeed, resource exploitation has often been the pathway out of poverty. Yet, whether one looks at the level of individuals or of nation states, the poor typically depend far more heavily on natural assets than do the rich (World Bank 2006, World Resources Institute 2005). And deepening poverty seems to go hand-in-hand with resource dependence and degradation, sparking much hypothesizing about a "resource curse".

The most important biophysical asset controlled by the poor is the health of individual family members. If they own nothing else, the poor at least have some control over their own labor power. But basic physiological functioning – particularly the capacity to work and to learn – depends in a seemingly highly nonlinear way on one's physical condition; so does change in health status, i.e., the law of motion describing human capital reflected in health status appears nonlinear (Dasgupta 1997). As the last section discussed, when laws of motion for assets become highly nonlinear, multiple equilibria can emerge naturally. Consequently, emerging empirical evidence – nicely summarized recently by Krishna (2006) – suggests that health shocks account for an overwhelming share of falls into persistent poverty, as observed in micro-level data from various places in Africa, Asia and Latin America.

Even leaving the complex dynamics of human health aside, the poor also depend relatively more heavily than do the rich on natural assets embodied in renewable natural resources (e.g., forests, soils, water, wildlife). The rural poor earn little-to-no capital gains, dividends or interest on financial assets, rental income on machinery or commercial or residential property, or even salary or wages outside the primary production sectors. They disproportionately earn a living by mixing their labor power with the fruits of nature. The returns to labor then depend on both the quantity and quality of the complementary natural resources available to them. When the human population grows but the stock of resources on which they rely remains fixed – or at least grows less quickly – then marginal labor productivity tends to fall. And within the primary sectors labor productivity – and thus income – depends heavily on the state of complementary inputs provided by nature. Farm workers are more productive on good soils than on infertile land, fishermen land greater catches from abundant fisheries, etc.

The laws of motion that guide natural resources therefore matter a great deal to the dynamics of labor productivity, incomes and investment among the rural poor. If natural resources typically degrade within a particular range of initial conditions and aggrade over (an)other range(s), labor productivity dynamics may then vary predictably based on initial resource conditions. Since renewable resource dynamics are indeed typically highly nonlinear – consider, for example, the generally logistic-shaped population dynamics of most fauna and flora – the possibilities for coupled collapse or abundance in human well-being and biophysical resources becomes quickly apparent (Perrings 1989, Barrett and Arcese 1998). These dynamics create non-convexities which generate poverty traps.

The most recent estimates by the World Bank (2006) indicate that roughly 70% of the natural capital in low income countries is found in agricultural and pasture lands. This makes understanding soil fertility dynamics especially important to understanding human welfare dynamics (Barrett et al. 2002, Pell et al. 2004, Marenya and Barrett 2007). An exponential decay function seems to describe soil organic matter (SOM) and closely related nutrient (e.g., N, P) dynamics in cultivated soils without soil fertility replenishment treatments, although the rate and asymptotic limit of the decay seems to vary markedly with soil properties (e.g., texture, mineralogy) and climate that cannot be managed.[8] There is a further possibility of critical thresholds at which rates of recovery from degradation shift markedly, as is suggested by the apparent contrast between the ease with which SOM recovers in labile pools in response to appropriate management interventions (e.g., short fallows, application of green manures or inorganic fertilizers) during the early stages of degradation and the difficulty of reversing degradation in stable SOM pools (Pell et al. 2004). The implication of such SOM dynamics is that crop yield response to fertilizer (or other nutrient amendment) application will be highly nonlinear with respect to soil state, often muted in heavily degraded soils, thereby discouraging smallholders from replenishing the nutrients they mine from their land with each harvest (Marenya and Barrett 2007).

The nonlinear dynamics of the natural resources on which smallholder livelihoods depend raises the possibility of multiple equilibria in both resource and human well-being states, a prospective explanation as to why collapse might occur alongside a homeostatic system with abundant resources and adequate (or steadily improving) standards of living. Note that this does not imply an automatic vicious cycle nor a ubiquitous "resource curse" but, rather, a system that may be highly resilient within some ranges, and hypersensitive in others. The sooner a detailed, empirical understanding emerges as to whether such multiple equilibria truly exist and, if they do, the relevant basins of attraction to each, the more effectively can interested parties manage ecosystems so as to facilitate escape from and avoidance of persistent poverty.

Poverty Trap Mechanisms' Applicability to Natural Resources

The three general classes of explanation of poverty traps offered in section 2 carry over quite naturally as we think about linked multiple equilibria in both human well-being and natural resource conditions.

Even when the strong assumptions of perfect markets, complete and perfectly enforceable property rights and perfect information hold – i.e., ruling out all three classes of mechanisms to generate poverty traps – resource conservation effort should increase with income, but at a diminishing rate, generating the usual convergence hypothesis result. However, constraints may impede equalization of the net marginal returns to current consumption and to investment in resource conservation or restoration that will maintain or increase future productivity, interfering with the natural tendency towards convergence in complete, competitive markets. This causes persistent divergence in welfare levels and resource states over time across the initial wealth distribution. For example, credit constraints foster underinvestment in natural resource conservation (Barrett et al. 2002, Antle et al. forthcoming), uninsured risk often leads to episodic overexploitation of nature, often when the resource is least able to sustain increased pressure (Barrett and Arcese 1998), and information asymmetries in labor markets – which results in familiar moral hazard and adverse selection problems – can lead not only to nutritional poverty traps (Dasgupta and Ray 1986, 1987), but also to overexploitation of land and thus to soil degradation and lower long-run productivity, even in the face of what seem added incentives to conserve resources (Bulte and van Soest 1999, Sylwester 2004).

Imperfect information about the state of – and perhaps especially change in – the natural resource base is an intuitive mechanism by which a poverty trap can emerge that is coupled to resource degradation. For example, given the nonlinear dynamics which seem to characterize soil fertility, significant informational lags in farmer perception of soil conditions, significant errors in those perceptions, or both, could lead to soil management practices that, while optimal given the farmers' perceptions, actually mismanage the resource and lead to resource collapse. Such lags and errors indeed appear realistic in at least some settings (Gray and Morant 2003). Predictable differences among farmers in their subjective beliefs concerning the law of motion governing SOM, for example, could lead to "inertial self-reinforcement" and multiple resource and welfare equilibria.[9] Similarly, slowly evolving social norms that do not adapt rapidly to emerging information can lead to poverty traps associated with resource degradation, as we discuss in the Madagascar case study in section 4.

The problems of externalities and coordination failures in generating resource degradation and impoverishment have been extensively explored in the literature. Weak institutions have been widely recognized as central to the problems of both resource conservation and poverty reduction in the rural tropics (Barrett et al. 2001). In particular, the prominence of common property regimes for natural resources in the rural tropics is often thought to lead to coordination failures that foster resource overuse and productivity loss. This leads naturally to the prescription that establishment and enforcement of private property rights will resolve this problem. But a substantial and influential literature has established convincingly that it is less the communal nature of property than open access – i.e., failure to set and enforce rules – that leads to problems (Larson and Bromley 1990, Ostrom, 1990, Bromley 1991, Baland and Platteau 1996, Gibson et al. 2005).

The growing focus on rules and equitable and constant enforcement has fostered a sharp growth in the literature on the role of corruption and the rule of law more generally on resource degradation and poverty (Deacon 1994). This quickly leads to questions of power. The correlation of wealth and power can lead to multiple equilibria in which wealthier and more powerful individuals can maintain control over resources, thereby creating incentives to invest in conservation, while poorer, more voiceless persons face considerable risk of asset loss, thereby dampening investment incentives and fostering resource degradation (World Resources Institute 2005). This line of argument has led to increased recent emphasis on good governance as central to the struggle to escape poverty traps and to avert ecosystem collapse. However, the emerging literature on corruption, governance, decentralization and the coupling of resource degradation with poverty traps remains distressingly atheoretical, while the empirical studies typically fail to account for other important control variables pivotal to the relationship between humans and natural resources and are fraught with various statistical problems (Barrett et al. 2006b, Barrett et al. forthcoming).

A range of possible poverty trap mechanisms therefore exist that integrate readily with the inherently nonlinear dynamics of natural resources to generate what might be termed "resource degradation poverty traps", i.e., low-level stable dynamic equilibria for both economic and ecological state variables. The problem is that we do not yet have very good diagnostic tools for screening among candidate mechanisms, indeed not even for establishing conclusively the existence of resource degradation poverty traps, as distinct from persistent poverty associated with slow improvement in incomes and resources status. Consider some examples from three quite different agroecosystems in sub-Saharan Africa.

Some African Examples

In this section, I aim to illustrate some of these prospective resource degradation poverty trap linkages casually by reference to empirical findings from a few sub-Saharan African settings I know well. But these remain relatively loose descriptions that underscore the importance of further research to explore these relationships rigorously and in detail. In each case, a few key features stand out. First, each case underscores that multiple equilibria appear to exist; these ecosystems are not condemned to collapse nor are their human resident managers inextricably trapped in grinding poverty. But without well-targeted interventions based on careful empirical identification of the mechanism(s) that generate the apparent poverty trap, such calamities are possible, even likely. Second, there is suggestive evidence in support of at least two of the three causal mechanisms outlined above, which complicates prioritization and targeting of interventions considerably. Third, empirical analysis of these processes is impeded by (i) the inherently nonlinear dynamics of the system, (ii) the feedback that renders most variables of interest endogenous to the system under study, and (iii) the paucity of data encompassing reliable measures of both biophysical and socioeconomic variables at common locations and intervals. Thus much of the literature remains at best suggestive. This is an area ripe for rigorous – and often multidisciplinary – investigation.

The Arid and Semi-arid Lands of East Africa

The first, core example Garrett Hardin (1968) used in describing the tragedy of the commons concerned herders in common pasturelands. Since pastoralists in the arid and semi-arid lands (ASAL) of east Africa, whose entire livelihood depends upon the livestock herds they can sustain on the grasses and water available on the rangelands, are also among the world's poorest populations by many metrics, these areas offer an excellent lens on the problem of resource degradation poverty traps. Recent research has established reasonably convincingly the existence of multiple equilibria in both human welfare terms – a poverty trap associated with distinct wealth levels – and localized range degradation alongside (seasonally) abundant forage in large parts of the east African ASAL (McPeak 2003, Lybbert et al. 2004, Santos and Barrett 2006).

The reasons for the apparent poverty trap are several. Market imperfections – not least of which, uninsured asset risk – create two distinct modes of pastoralism, a low-level equilibrium characterized by sedentarized livestock keeping of one or two cows in small, poor settlements subject to serious, but only localized range degradation, and a higher-level equilibrium based on traditional, transhumant grazing of large herds sustained by long distance treks to areas that retain abundant forage and water (Lybbert et al. 2004, Santos and Barrett 2006). Impoverishment and range degradation seem to go hand-in-hand, exactly as Hardin described,[10] and are magnified by human population growth in an area facing receding available grazing lands. But the tragedy of the commons applies only over a specific geographic and economic range. Those conditions by no means apply to the whole of the region, indeed only to a very small proportion of the land area as recent, careful empirical studies find no support for classical commons effects – i.e., one pastoralist's herd size having an adverse effect on the productivity or survival of another pastoralist's livestock (Lybbert et al. 2004, McPeak 2005). This certainly seems a multiple equilibrial system in both ecological and economic terms.

The challenge of resource degradation poverty traps in the east African ASAL transcends herd sizes and market imperfections, however. Historically, a clan or ethnic group's grazing areas typically have flexible and contested boundaries. As a result, environmental resource management becomes closely bound up with issues of conflict management, as setting and enforcing rules so as to coordinate expectations and actions becomes essential to prevent collapse, not just of the fragile range ecology but also of pastoralist communities into violence and destitution (Haro et al. 2005, Munyao and Barrett forthcoming). It seems unlikely that one could surmount the poverty trap problem in the pastoral areas of the east African ASAL without tackling both the market imperfections and coordination/ institutional issues jointly.

Western Kenyan Maize Systems

Shepherd and Soule (1998) found, based on a simulation model calibrated using data collected across a range of western Kenyan farms, that soil nutrient mining by poorer farmers unable or unwilling to invest in soil fertility replenishment can co-exist alongside stable soil quality among better-endowed farmers. This important finding is one of the clearest empirical examples in the literature of a resource degradation poverty trap.

Plot- and farm-level survey data collected over the period 1989-2004 in a village, Madzuu, in Vihiga District, western Kenya, and subsequent data collected along a chronosequence of western Kenyan farms provide corroborating empirical evidence of the patterns Shepherd and Soule (1998) first described (Barrett et al. 2006a, Marenya and Barrett 2007). Those who remain non-poor over time started off with statistically significantly higher endowments of land, improved livestock and educated family members, as well as greater and more remunerative off-farm employment to generate the cash necessary to invest in chemical fertilizer and other critical integrated soil fertility management interventions. As soil N and P stocks decline after a few decades' continuous cultivation in annual food crops and as farms gets subdivided in the face of human population growth, the better off farmers can afford to purchase and plant tea stems and to forego any earnings from the land converted to perennials during the roughly two years it takes tea bushes to mature and generate marketable leaves. The tea bushes' roots provide outstanding erosion control, however, and the local tea factories' natural monopsony – due to the need to process tea leaves quickly after picking – enables them to provide inorganic fertilizer on credit secured by future delivery of tea leaves. Those who can afford to invest in conversion from maize to tea as soil quality declines thereby escape the seasonal liquidity constraints that impede soil fertility replenishment by poorer neighbors. A homeostatic system of reasonably fertile soil conditions and adequate incomes results for these households.

Meanwhile, those who collapse into poverty all traced their decline to shocks that caused them to lose critical land, livestock or human assets, initiating a spiral from which their family has not recovered. Those who suffer persistent poverty articulate less concern for conserving soil fertility and make fewer efforts to do so, presumably reflecting lower conditional (constrained) returns to investment in degraded soils for the poor. They point to certain higher-return activities as beyond their reach for want of financial capital, education (commonly due to inability to pay school fees), the social connections necessary to secure remunerative full-time employment, or some combination of these. These obstacles dampen the productivity of their limited labor, land and livestock holdings relative to better-off neighbors. The resulting household-level asset dynamics exhibit multiple stable dynamic equilibria (Figure 1), with less than 20% of the population clustered around the higher dynamic equilibrium – at only about $1.50/day per capita – and the rest distributed around, and presumably converging toward, the lower level equilibrium beneath the poverty line, at less than $0.50/day per person (Figure 2).

Parallel plot-level trials find evidence of nonlinear dynamics in soil fertility and in yield response to soil fertility amendments in this same area, underscoring that low investment in maintaining or reconstituting soil fertility may be rational for some poorer farmers while soil fertility maintenance is attractive for wealthier farmers (Marenya and Barrett 2007). The result seems to be a system characterized by multiple soil fertility equilibria and associated levels of per capita income, driven in large measure by imperfections in markets for credit and insurance.

Unfortunately, the story seems to get somewhat more complicated still. Farmer perceptions of soil quality appear only weakly related to laboratory measurements of SOM, nutrient stocks, etc. and preliminary, qualitative assessments raise the possibility of significant informational lags, biases or both in farmer assessment of soil fertility dynamics. There remains scant empirical evidence on the relationship between farmer perceptions of soil quality and of soil quality change induced by conservation and fertilization, on the one hand, and farmer investment in maintaining soil quality, on the other. This is an important gap, as the imperfect learning and bounded rationality mechanism may well be at play as well in driving resource degradation poverty traps in this region.

The coordination failures mechanism may now play an important role as well. Nutrient-depleted soils in sub-Saharan Africa have become infested with the parasitic weed *Striga hermonthica*, with yield losses now over US$7 billion annually (SPIPM 2003). Prevention of *Striga* encroachment depends on maintaining high soil fertility and moisture, which is difficult in rainfed lands with infrequent rotation or fallowing. Once established, "witchweed", as Kenyan farmers understandably call the plant, has proved resistant to conventional methods of weed control via herbicides and hand or mechanical weeding. A single *Striga* plant produces thousands of tiny seeds that are difficult to notice, most of the damage to the crop occurs before the parasite emerges from the ground and can be readily identified, and the seed can remain dormant but viable in the soil for many years. *Striga* is therefore difficult to eradicate because a single surviving plant can recolonize a large area in a single season. And with so many lightweight seeds, it spreads readily from farm to farm vai wind, water, animals and humans. Coordinated measures are essential for effective eradication because the returns to an individual farmer's efforts to block the entry of (or to eradicate) *Striga* on his fields are an increasing function of neighboring farmers' efforts at weed control. It has proved exceedingly difficult, however, to organize communities to combat *Striga* in spite of the parasitic weed's considerable costs. This seems to be especially true in villages with large numbers of recent immigrants, inter-clan frictions and other social phenomena that dampen the strong ties necessary to resolve such coordination problems (Barrett 2005). Thus crop yields and soil quality continue to decline, but in this case, due in large measure to the coordination failures mechanism behind poverty traps.

Rice Systems in Madagascar

Madagascar is perhaps the closest one comes at the macro level to a resource degradation poverty trap. It is at once one of the world's poorest countries and one of the global environmental community's greatest concerns – a "hot spot" – due to alarming rates of loss of endemic species, forest and topsoil from the island nation. Why does this twin crisis persist in the wake of at least two decades' concerted efforts at both environmental protection and poverty reduction in Madagascar?

More than three-quarters of Madagascar's poor live in rural areas and more than 70% of the population grows rice, which occupies more than half of the nation's cultivated land. The key to understanding rural poverty and resource use thus lies in understanding the dynamics of Malagasy rice systems. Yields are very low, with median yields unchanged over the past quarter century at roughly two tons per hectare. Quite a few different methods of rice intensification have been promoted in Madagascar over the past twenty or so years, but none has yet gained a sufficiently solid foothold to improve productivity appreciably. One consequence is continued deforestation, habitat loss and soil degradation – from both massive erosion that leads to dramatic landslides (*lavaka*) and severe soil nutrient depletion – due to extensification and unsustainable intensification without adequate soil nutrient amendments. Resource degradation poverty traps appear very real in rural Malagasy rice systems.

Part of the problem stems from market imperfections, some of them caused by the formerly Marxist government's misguided attempts at state control over agricultural inputs, land, credit and food distribution. But severe problems persist, as financial liquidity constraints generally inhibit farmers' uptake of fertilizers and other inputs needed to sustain soils and reduce pressures to extensify through deforestation, as well as adoption of promising, low-input, yield-increasing technologies (Moser and Barrett 2006). Uninsured risk likewise encourages deforestation (Barrett 1999), while high transactions costs in a nation with poor transport infrastructure and difficult topography create significant disincentives to the use of purchased inputs and overuse of lands that are relatively ill-suited to intensive cultivation (Minten et al. 2006). The canonical market imperfections based explanations of poverty traps seem to fit the Malagasy rice systems case well.

Yet other factors matter a great deal as well. Among rural Malagasy, social customs are extraordinarily important and limit adaptation to emerging evidence of the need for new ways of managing forests, land, water and wildlife on the island. For example, although highland Malagasy farmers say they cannot afford inorganic fertilizers or improved seed, they routinely pay extraordinary sums to exhume and reshroud dead ancestors every 3-10 years – an elaborate ceremony known as *famadihana* – and to travel long distances and contribute significant sums for *famadihana* for even distant relatives' ancestors. Further underscoring the social and spiritual importance of death rituals among the Malagasy, several ethnic groups have strong behavioral expectations that households will sacrifice cattle when a household member dies. But because soil fertility and rice productivity are strongly increasing in cattle holdings due to manuring and animal traction services that are imperfectly tradable, livestock sacrifice implies a long-term productivity decline for the household, thereby increasing the probability of subsequent undernutrition and illness leading to death, creating a resource degradation poverty trap (Barrett 2005). There is significant resistance to changing these behavioral expectations in spite of their obvious, and sometimes catastrophic, cost in both human and environmental terms.

And as in Kenya, coordination problems abound and compound the challenges facing rural resource managers and poor farmers. Water management is extremely important in rice systems. One intriguing new method of growing rice – known as the system of rice intensification (SRI) – requires more careful water control as fields are regularly flooded then dried, rather than left under standing water. This becomes problematic along the irrigated rice perimeters in which most lowland rice is grown because all farmers must agree to use similar methods and varieties in order to coordinate the capture and release of water across plots effectively. Meanwhile, those cutting upland forests inadvertently disrupt seasonal hydrological cycles and stimulate increased surface erosion, leading to siltation of irrigation channels and diminished lowland rice yields. Of course, this induces increased extensification along fragile hillsides, reinforcing the problem. Those communities that have managed to coordinate water use and forest access effectively have been able to achieve and maintain higher rice yields and more stable forest margins than those that have struggled to resolve the coordination challenges facing Malagasy rice producers. Just as in western Kenya and the arid and semi-arid lands of east Africa, multiple mechanisms seem to drive apparent resource degradation poverty traps.

Policy Implications

Recent estimates suggest that when natural resource depletion and population growth are taken into account, most low-income countries face declining per capita wealth while most high-income countries enjoy increasing per capita wealth (World Bank 2006), with much of the birfurcation in dynamics directly attributable to degradation of natural resources, thus mirroring and reinforcing the "divergence, big time" observed in real per capita income data across countries (Pritchett 1997). This apparent coupling of resource and human population and welfare dynamics raises pressing questions about the possibility of resource degradation poverty traps. So what can and should development and conservation agencies, donors and governments do?

At the most general level, there is a clear compulsion to act. The clear implication of the poverty traps hypothesis is that intervention is essential if people are to escape and avoid persistent poverty. If it is likewise true that the dynamics of renewable resources are closely coupled to the dynamics of the well-being of the human populations that depend on those resources, then intervention is equally essential to avert ecosystem collapse.

Recognizing the need for some sort of intervention is the easy part, however. While intervention is valuable, indeed essential, the multiple causal mechanisms that can generate poverty traps make it terribly difficult to identify appropriate interventions. For example, if economically dysfunctional institutions are the main problem (à la De Soto), then injections of capital (as advocated by Sachs 2005) intended to surmount asset thresholds are unlikely to work. Conversely, if inadequate resources are the primary problem, not economically dysfunctional local and national institutions (i.e., if Sachs, not De Soto, is right), then the extraordinary attention presently paid by development institutions to governance questions will likely prove just wasted effort with a heavy opportunity cost. The most plausible, but also most complex, scenario is that different mechanisms are at play at once, with different ones dominating at different scales of analysis, with capital shortfalls at the micro levels of individuals, households and firms reinforced by coordination failures at meso levels of communities and markets, which are in turn reinforced by economically dysfunctional institutions at national and regional scales that in turn impede coordination and access to capital, what Barrett and Swallow (2006) term “fractal poverty traps” due to the self-similarity across scales of the core characteristics, albeit with different causal mechanisms.

We still know distressingly little empirically about these various mechanisms that underpin poverty traps and resource degradation in the rural tropics. The good news is that makes this an especially fertile area for research, both in developing appropriate methods for identifying dominant causal mechanisms and for evaluating interventions, and in establishing generalizable rules of thumb for policy design to overcome poverty traps and renewable resource degradation.

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Figure 1: Estimated asset index dynamics for Madzuu, 1989-2002, based on nonparametric kernel autoregression of Sahn-Stifel asset index. Reproduced from Barrett et al. (2006a).

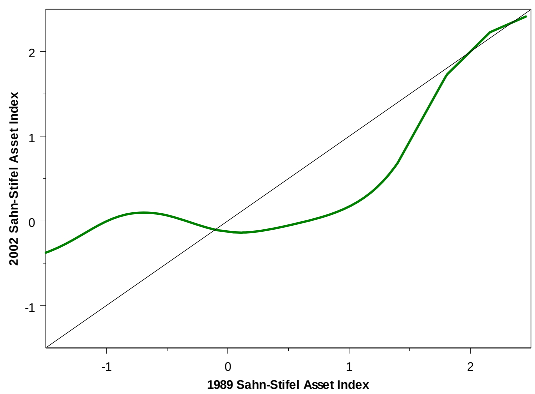
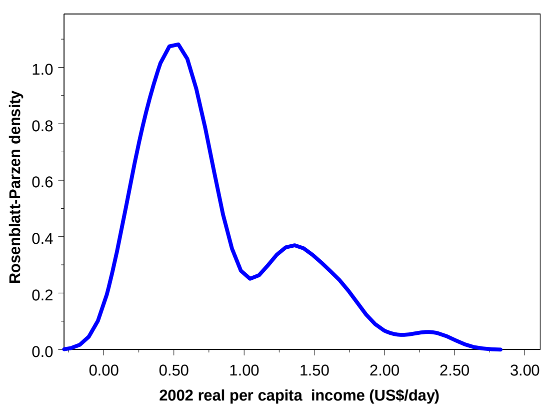


Figure 2: Per capita daily income distribution, Madzuu, 2002, based on Rosenblatt-Parzen density. Reproduced from Barrett et al. (2006a).



Notes

[1] The key is that equilibrium paths differ as a function of initial conditions. There may not be a steady state; the system could instead be chaotic or follow cycles. In the remainder of this paper, however, I assume a steady state exists for each equilibrium path.
[2] See Muradian (2001), Beisner et al. (2003), Scheffer and Carpenter (2003) and Reitkerk et al. (2004) for good reviews of the relevant literature.
[3] By "highly non-linear" I mean something that cannot be represented by a low-order polynomial expression, certainly not first or second order, so as to allow for inflection points in the law of motion.
[4] Of course, the stable dynamic equilibrium will evolve as the underlying mappings, $f^m(\cdot)$, change due to improvements in technologies and institutions. Hence the dual importance of asset accumulation and technological and institutional change for economic growth: within an institutional-technology regime, assets are determinant, while institutions and technologies likely dominate over longer time spans.
[5] Mookherjee and Ray (2000) refer to this as "historical self-reinforcement".
[6] Diamond (1982) is a canonical example.
[7] It is important to note the modifier "economically" because many of the institutions that have emerged have important cultural or social purposes that, unfortunately, come at the cost of incentives – perhaps especially for the poor – to innovate and accumulate productive assets. Many such institutions – e.g., social sharing arrangements implying high marginal rates of informal taxation, complex property rights with multiple claimants to incompletely alienable property, etc. – are deemed highly desirable by many individuals, thus they plainly play a valued function. Such institutions are thus dysfunctional in the important, but limited, sense that they fail to encourage behaviors that yield medium-to-long term increases in investment and incomes. I thank Felix Naschold for helpfully pushing me on this point.
[8] Johannes Lehmann points out (personal communication) that in western Canada (Alberta), 100 years of cropping without soil nutrient amendments reduced SOM by only 5-10%, while similar experiments in the western United States (Oregon), South Africa and Kenya show declines of 40%, 50% and 60-70%, respectively.
[9] For example, there could be important differences between those who occupy and manage for many years land held under secure tenure, versus those who control a parcel for only a short period due to tenure insecurity who thus do not know a plot's history and thus have far less information to use in land management. This is one of the under-recognized problems of tenurial insecurity.
[10] Hardin, however, posited a unique low-level equilibrium, not the multiple equilibria recent studies in this region consistently find.