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Environmental Economics and the Rural Poor: Distinct Challenges and Solutions
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In the developing world's peasant economies – where households' principal occupation is agro-pastoral production on a semi-subsistence basis – environmental resources play a distinct economic role and face distinct threats from those commonly emphasised by environmental economics. Namely, such areas face different environmental problems and involve different actors with different economic priorities. As a result, environmental economics looks different there, particularly the nature and application of environmental valuation (Table 1).

1. Natural resource depedence as an opportunity

Poor countries are predominantly rural and agricultural, with a large proportion of rural households living in 'low potential' agricultural areas[1], typically as farmers practicing semi-subsistence agro-pastoral production. Such areas are home to some 1.8 billion people worldwide, including most of the rural poor in developing countries (Pender et al 2001). During the period when agricultural subsidies were common (1960-1990), farmers in such areas often used Green Revolution inputs such as hybrid seeds and chemical fertilisers and pesticides, since they were readily available and cheap. Yet following structural adjustment and the abolition of input subsidies, use of 'purchased' inputs fell sharply in 'low potential' areas, and is now often minimal (Upton 1996).

As such, these areas are often 'essentially biomass-based subsistence economies' (Dasgupta 1997), where the rural economy relies critically on the continued viability of local natural resources. Specifically, the environment provides goods such as fuel, timber and medicine and services such as fertile soil, viable pastures and stable hydrology. The close association of agriculture with the environment in peasant economies is implicit in discussions of the 'population-agriculture-environment nexus', which suggest that rapid population growth, agricultural stagnation and environmental degradation are linked phenomena requiring integrated solutions (e.g., Cleaver & Schreiber 1994; World Bank 1992:27).

This dependence on natural resource stocks in these areas represents an opportunity for the environment and associated goods and services. After all, if rural people depend on these resources for their survival, they face strong incentives to ensure the resources remain viable and are managed sustainably. Moreover, 'regenerative technologies' have been identified that represent proven, viable means of reversing this process at farm and community level.

Regenerative technologies such as soil and water conservation, agroforestry, or integrated pest management actively maintain critical natural resources, as opposed to relying on nature's bounty or purchases of external inputs. Specifically, they facilitate processes of natural regeneration via targeted, intensified labour inputs and harness symbioses between farm components such as crops, livestock and trees. Such 'sustainable agriculture' farming systems can both increase efficiency and minimise the need for external inputs (Pretty 1995), yet rely strongly on local knowledge due to their complexity (Farrington 1998).

Because it involves 'investments' in natural capital, sustainable agriculture can restore productive potential lost due to resource degradation or increase the overall carrying capacity of land (Pretty et al 1996). As such, it represents a means of meeting growing demands on land due to population pressure (Scherr & Yadav 1996; Shah et al 1993) and turning the 'vicious' circle of agricultural stagnation and environmental degradation into a 'virtuous' circle of growth and regeneration. Moreover, such practices are accessible to farmers in marginal areas due to their emphasis on inputs already existing in rural communities rather than external inputs to which they may lack access (Altieri et al 2001).

The promise of sustainable agriculture has been amply demonstrated. Based on a multi-country analysis, Pretty et al (1996) report that adoption of regenerative practices led to large productivity increases in low-potential, food-deficit areas of developing countries. On average, adopters had doubled their cereal production since adoption in addition to diversifying farm outputs, notably through production of useful tree products. Similarly impressive results have been obtained in Shinyanga District, Tanzania (Rao et al 1998; HASHI/ICRAF 2000), Kondoa District, Tanzania (Dejene et al 1997), and Zambia's Eastern Province (Franzel et al 2002).

2. Yet this promise hasn't materialised

Despite such promise, 'low potential' areas are not typically characterised by careful husbandry of local natural resource stocks. On the contrary, such resources are often 'mined' – i.e., degraded to the point of depletion – by rural people, ostensibly because households face perverse incentives associated with factors such as acute poverty and insecure property rights (Prakash 1997).

[1] By definition, 'low-potential' agricultural lands face difficult agro-climatic conditions, such as poor soils, low or unreliable rainfall, steep slopes and short growing seasons. They may also be poorly provisioned with infrastructure such as roads, markets and irrigation works or services such as extension, schools and health centres (Pender et al 2001).

At the same time, adoption of regenerative technologies has generally been low (Oram et al 1998), perhaps due to competing demands on labour (Kayombo & Mrema 1994). Some households adopt them but many do not. This occurs despite the longstanding policy emphasis on addressing perceived constraints to technology adoption, notably unfavourable tenure arrangements, poor transport infrastructure, erratic input supply, and lack of credit, information or tools (Feder et al 1985).

It is true that numerous studies have reported spontaneous, rapid diffusion of advantageous technologies. Yet these cases have generally involved 'sexy', marketable products with short payback periods. Examples include hybrid maize in northern Nigeria (Smith et al 1994), hybrid wheat in Palanpur, India (Lanjouw & Stern 1993), coffee and tea in Kenya (Bevan et al 1989), cocoa in Sulawezi, Indonesia (Pomp & Burger 1995), and tobacco in Malawi (Place & Otsuka 2001). By contrast, regenerative technologies tend to provide mundane agricultural support services (e.g., fertilising soils) and to involve longer payback periods.

Other evidence suggests that peasant farmers in developing countries are engaged in a continuous process of endogenous technological innovation (Biggs & Clay 1981; Reij & Waters-Bayer 2001). Yet the innovations in question tend to involve relatively minor adaptations of current practice, notably experimentation with new crop varieties or planting arrangements. Meanwhile, bolder innovations such as experimenting with agroforestry are comparatively rare (Nielsen 2001).

The end result is widespread resource degradation that is thought to be a root cause of rural poverty (HDR 1998:56). Notably, the poor performance of agriculture on low-potential lands is increasingly attributed to resource degradation (Scherr & Yadav 2001), due to its adverse impact on land and labour productivity. Moreover, anecdotal evidence of resource degradation is abundant. For instance, cassava yields in Nigeria fell from 10.8 to 2 tons per hectare as the average fallow period fell from 5.3 to 1.4 years (Lagemann 1977). Similarly, women and children in parts of East Africa are reported to walk ever farther to find fuelwood, often many hours each day (Dewees 1997).

3. Technology adoption by peasant households as pivotal

Whatever its causes, depletion of natural capital creates worrisome trends – for the current and future welfare of rural communities, as for broad environmental objectives such as coping with climate change and maintaining biodiversity – suggesting a need to find ways to reverse it. Since the day-to-day managers of vast expanses of rural lands are agricultural or pastoral households, the battle for the future viability of environmental resources in such areas will be won or lost based on the actions of innumerable rural households. Arguably, this is also the battle for the future viability and security of rural livelihoods, given the reliance of rural production in these areas on environmental goods and services. In both cases, the critical decisions regarding management and technology adoption are taken at farm level, since agriculture as a sector is characterised by many producers making independent decisions (Timmer 1989).

Taken together, these factors have led diverse authoritative observers to conclude that adoption by farmers of intensive NRM practices is pivotal. Thus, Buck et al (2004) cite securing farmer adoption of its strategies as the great challenge facing both agriculture and environmental management, while Barrett et al (2002) argue that technology adoption and scaling up of intensive NRM practices is the key challenge facing African agriculture. Similarly, Lee et al (2001) cite numerous examples of synergistic strategies that raise living standards while regenerating the local environment, but report that the record of their use is 'very mixed', i.e., that they enjoy only limited adoption. The present paper suggests that this emphasis on adoption of intensive NRM strategies as a pivotal issue highlights a clear role for environmental economics in ongoing poverty reduction efforts, as seen below.

4. Environmental economics and privately-owned farms

As conventionally conceived, environmental economics tends to focus on ensuring that economic actors have secure access to the long-term benefit stream of the environmental resources they manage. This mirrors the focus within economics generally on incentives. Policy towards addressing poverty in peasant economies likewise tends to focus on incentives, as exemplified by its emphasis on securing property rights, raising farm-gate prices, and providing access to credit. Among other effects, such policies are expected to bolster incentives facing smallholder farmers to conserve or 'invest in' local stocks of environmental resources.

One key focus is valuation of environmental resources to ensure the full economic significance of environmental resources is heeded by economic actors. Once such values are known, mechanisms can be put in place to ensure they are reflected in private management decisions. This process is known as 'internalising' externalities, since it ensures that external costs and benefits are treated by economic actors as though they were private values. Thus, private ownership is seen as the ideal endpoint that government mechanisms seek to simulate, since given private ownership managers are expected to capture the long-term benefit stream of resources, and hence face incentives to conserve and perhaps invest in the relevant resource stocks. While in some respects universal, this narrative must also be adapted to the distinct context represented by poor rural districts of developing countries.

Perhaps the key distinguishing factor of these areas is that vast swathes of the rural lands currently plagued by environmental degradation are *already* privately owned by peasant households. That is, the environmental problems facing peasant economies occur largely on private lands. As such, incentives for rural people to conserve or 'invest' in natural capital are often already in place, and owner/managers are expected to manage farm-based natural resources optimally. Incentive-based interventions may thus be ill-suited to addressing the environmental challenges facing peasant economies.

Obviously, depletion of private resource stocks may sometimes represent optimal management, for instance if the household in question faces elevated personal discount rates or lacks secure tenure to their land. Notably, it has repeatedly been suggested that households may degrade natural resources or fail to adopt regenerative technologies because this makes sense given their poverty and the constraints it imposes, as seen above. Moreover, the incentives to conserve or 'invest' in natural capital may be clear yet weak and hence need to be bolstered, for instance by raising farmgate prices or developing improved regenerative technologies.

Despite the logic of these arguments, several factors cast doubt on this conventional interpretation of the twin phenomena of ongoing resource degradation and limited adoption of regenerative technologies. These same factors cast doubt on the relevance of incentive-based interventions to addressing environmental concerns in the vast areas where peasant farming is the dominant livelihood. One factor is that generally stagnant agricultural production in these areas contrasts sharply with often impressive gains where farmers have adopted 'sustainable agriculture' practices to bolster natural capital stocks. On the surface, this observed dichotomy suggests that advantageous opportunities are being routinely squandered. A second factor is a set of a priori ideas about local knowledge vis-à-vis NRM given emerging NR scarcity. A third factor is fresh evidence reported below from a peasant community facing emerging natural resource scarcity.

5. Problematic local knowledge?

Clearly, households may allow degradation and/or fail to adopt intensive NRM practices on their private lands because they face unfavourable incentives. Yet an alternative possible explanation for these outcomes is problematic local knowledge vis-a-vis NRM. It is hypothesised that during periods of emerging NR scarcity, households with similar needs and assets will hold fundamentally distinct ideas about optimal NRM, some of which are better adapted to contemporary challenges than others. This may be termed the 'knowledge failure' model, given its similarities with the concepts of 'market failure' and 'institutional failure'. All refer to situations in which a system fails to deliver a beneficial outcome due to constraints neglected by idealised conceptions of how it should work.

Obviously, farm households determine their resource management strategies based on perceived self-interest given existing constraints. But tangible incentives created by local resource and institutional constraints are perceived via the prism of peoples' knowledge, which may colour these perceptions.

The NRM decisions of peasant households are informed by local knowledge (LK) derived principally from their community's historical experience and their own observations. LK is portrayed in the literature as sound, dynamic and well-adapted to local conditions. "LK is the basis for local-level decision making… and the main asset [of the poor] to invest in the struggle for survival. It is developed and adapted continuously to gradually changing environments" (World Bank 2002). Within development, it is often used to tailor institutional interventions to the local context via participatory approaches based on the idea that locals know best about their context and needs. Local knowledge of natural resources is thought to be particularly good, since rural people live and work in close proximity with these resources. As such, sound management and effective adaptation to change are thought to be especially likely in the case of natural resources.

By contrast, the present paper suggests that LK vis-à-vis NRM may be particularly problematic. Notably, economic actors may overlook incentives to intensify NRM under certain circumstances, namely given emerging natural resource scarcity. While farmers may face incentives to adopt intensive management strategies to secure needed NRs – e.g., cultivating trees when they become scarce – they may neglect them due to failing to recognise the shifting shadow prices of key NRs. Notably, damaging environmental degradation may be allowed to proceed, while accessible, advantageous opportunities to invest in natural capital may be neglected. In this light, the common failure of rural households to adopt intensive NRM practices may be largely due to households neglecting key environmental values in their day-to-day management decisions. That is, it may be due to problems with 'implicit valuation', as seen below.

Ensuring favourable incentives may thus be 'necessary but not sufficient' to secure efficient, long-term management of environmental resources. The trouble is that where economic actors fail to *recognise* shifting incentives vis-à-vis NRM due to shifting institutional and/or resource constraints, these incentives may 'fail to bite'.

The danger to peasant economies is that households may not recognise the point at which regenerative practices become advantageous, and hence fail to make the transition from relying on natural regeneration to actively facilitating regeneration. This is most likely to occur where NR scarcity emerges rapidly, since in such cases past experience may be a poor guide to current management challenges that involve 'hitting a moving target'[2]. While the tendency to take natural regeneration for granted may plague NR managers generally[3], it is especially worrisome in the case of peasant communities, who depend on NRs for their livelihoods and can ill-afford missed opportunities (Figure 1).

6. A priori reasons to problematise LK vis-a-vis NRM

The responsiveness of LK to change may be problematic during times of emerging NR scarcity. This follows from two characteristics of NRs, namely that they were historically abundant and tend to regenerate spontaneously under normal conditions. Both traits may encourage beneficiaries to view NR goods and services as 'free gifts of nature' and hence to take their presence and reproduction for granted. While such a view is unproblematic as long as NRs are abundant, this may change where NRs become scarce yet provide needed goods and services.

Problems with the responsiveness of LK to change may be exacerbated by cultural embedding, whereby ideas about appropriate NRM developed in the past – when NRs were often abundant – become set social norms possibly reflected in local mythology. Thus, rural societies with a strong sense of tradition may have difficulty adapting to major changes to the rural context. "If you are steeped in social norms of behaviour... you do not calculate every five minutes how you should behave. You follow the norms." Yet established practices remain optimal only so long as the local context remains roughly constant (Dasgupta 1996).

A third factor that raises questions about LK's capacity to accurately inform NRM is misguided information provision to rural communities. Such information may sometimes mislead and obfuscate instead of informing and empowering[4]. Its impact could therefore be adverse, given the likely influence on LK of views and strategies advocated by powerful outside actors such as extensionists.

Besides such knowledge supply issues, the demands on LK are great, given the complexity of NRM decisions at times of emerging resource scarcity and the fact that NRs typically lack prices. Most fundamentally, the fact that NRs may be generated either naturally or via human intervention raises questions about when the latter becomes advantageous. At this point, maintaining optimal NRM may require radical management innovations such as cultivating trees to provide fuel rather than gathering wood from the bush or actively maintaining soil fertility rather than relying on fallowing. Otherwise, NR dynamics are inherently complex. Notably, the growth rate of a given NR depends on stock size, different NRs may interact either symbiotically or competitively, and natural capital investments typically involve non-linear, multi-year payback periods. Finally, LK must integrate diverse natural and social factors (Table 2).

7. 'Implicit valuation' of environmental resources

Where such 'perception time-lags' occur in this distinct economic and environmental context, environmental valuation may take on a very different aspect. Namely, it may involve ensuring that rural households recognise the shifting role of natural resources in the farm system and the shifting private value of competing NRM options. As such, securing effective environmental valuation may involve information provision, or finding a means of conveying these differing roles and values to rural people accustomed to another set of roles and values.

The fact that environmental resources typically lack prices means that peasant farmers must base their management decisions on 'implicit valuation' of these resources. Implicit valuation involves assessing the net value or 'implicit price' of each key natural resource based on the goods and services it provides and any costs it imposes. This process is conducted entirely within farmers' heads, i.e., without clipboards, pencils, or methodological tools such as net present value. Each resource is simply 'sized up' by farmers. For instance, they assess the value to the household of goods such as fuelwood and fodder and services such as nutrient and hydrological cycles.

In the case of peasant economies, the analogue of conducting formal environmental valuation and 'getting the prices right' is thus ensuring that farmers are fully aware of key environmental values. While implicit valuation may not be as rigorous as formal valuation, it is systematically conducted as part of households' day-to-day management decisions. This contrasts with formal valuation, which necessarily raises the question of whether conducting the valuation is justified by the likely gains from better-informed decisions (e.g., Glass & Corkindale 1995; Newbery 1995).

8. The need for such theory

Given concerns about farm and natural resource management in these communities, some policies seek to address potential knowledge gaps vis-à-vis management strategy. Notably, ongoing efforts at extension service reform seek to

[2] This contrasts with the case of LK vis-a-vis *static* phenomena such as ethnobotany, whose accuracy is often cited as evidence of the subtlety of LK.
[3] For instance, Arrow et al (1995) suggest that economic policy has tended to ignore the environment.
[4] For instance, they may advocate technologies that are inaccessible to poor households or condemn useful traditional practices.

increase farmers' technical knowledge, while village-based 'farmer field schools' specifically target knowledge of natural resource management. Yet theory has failed to grasp the nettle of examining how and why such gaps may occur and their precise nature, despite such questions being central to the capacity of policy to effectively address them. Why has this happened? A priori ideas underlying current theoretical frameworks are the obvious culprit.

The idea that rural managers may fail to recognise key environmental values not only goes against environmental economics, but various other disciplines as well. Notably, both anthropology and agricultural economics emphasise the fundamental soundness of the local knowledge informing the management decisions of peasant households. Thanks to diverse theories dovetailing around a common view of local knowledge, the possibility that rural households may face knowledge gaps vis-à-vis natural resource management represents a conceptual 'blind spot'. This suggestion is also frowned upon politically, since it superficially seen as harkening back to the 'bad old days' of viewing peasant farmers as 'ignorant', 'lazy' and 'irrational'.

Despite being neglected by theory generally, the possibility that local knowledge vis-à-vis NRM may be problematic is of great practical importance. Such knowledge gaps could represent a key constraint on rural welfare, impeding rural people from harnessing major environment-economy symbioses. Moreover, information provision initiatives continue regardless, yet without the benefit of critical assessment of communities' knowledge needs. Finally, problematising local knowledge need not imply the slightest denigration of rural people, merely a recognition of a perfectly understandable and all-too-human reaction to rapid change and emerging resource scarcity. The remainder of the paper presents fresh evidence from Tanzania then draws policy implications.

9. Empirical study conducted in Shinyanga District, Tanzania

An in-depth study of rural livelihoods in Shinyanga Rural District, Tanzania examined these issues. The study involved interviews with 350 households in twenty villages in a low potential agricultural area that resembles Fimela District in terms of climate, vegetation and dominant livelihood strategies. Namely, this is a remote, semi-arid area with irregular rainfall and widely scattered trees and bushes. Livelihoods are mostly agro-pastoral and production is largely for home consumption, though many also grow cash crops. The area is food-insecure, however, often failing to meet its peoples' caloric and protein needs (Government of Tanzania 2000).

Households were selected via two-stage sampling – random selection first of villages then of households within villages – to maintain randomisation without imposing unmanageable logistical demands on the field team. Households were asked to cite the tree species most significant to them, then to specify the products or services derived from them, and any harmful impacts they may have. Qualitative comments on trees and tree management were also recorded.

The tree data examined involved only the three tree species cited by each household as 'most significant' to it. Taken together, eleven different species were cited by at least ten percent of survey households, including seven non-fruit trees, two exotic fruit trees and two indigenous fruit trees. According to the World Agroforestry Center, these trees provide diverse products and in some cases help fertilise soils (Table 3).

Data were gathered on diverse aspects of households' resources, management practices and knowledge. The econometric analysis focused on examining the determinants of different tree management strategies practised by households. Different strategies represent different ways of allocating household resources in pursuit of livelihood objectives. Given increasing pressure on natural resources, one fundamental distinction is whether households actively facilitate the regeneration of farm-based natural resources, instead of simply relying on natural regeneration. A second is the degree and nature of any such active facilitation. Given the complex role of trees in smallholder farm systems, tree management represents a case where knowledge is particularly likely to be problematic.

10. Analyses conducted

The specific models analysed reflect the key distinctions among household tree management strategies. The first model identifies the determinants of total farm tree numbers, without regard to whether trees grew naturally or were cultivated, while the second model assesses whether the household sold any tree products. Models three and four examine those households that do not cultivate trees. Model five examines households that cultivate exotic fruit trees, while model six considers the case of households that plant and water trees other than exotic fruit trees. Model seven examines the intensity of tree cultivation, model eight the types of tree deemed most significant to the household, and model nine the location of farm trees.

These various tree management models shed light on the determinants of diverse tree management patterns. Each emphasises a different aspect of tree management and provides a different window onto management strategies and their determinants. The more aggregated models show what factors distinguish one particular aspect of tree management, while the complex models show those factors that distinguish more specific tree management strategies.

These models were analysed using logistic regression to identify their various determinants and overall explanatory power. Each model was initially analysed using only resource variables, after which the analysis was broadened to include knowledge variables. The integration of knowledge variables included two distinct stages. First, three outside influence variables – including two knowledge proxy variables and a religion variable – were factored into models as potential determinants. The knowledge proxy variables emphasised households' access to outside information and hence 'modern' knowledge, as commonly factored into studies of farming outcomes, while the religion variable represented outside influence on attitudes. Second, a set of variables representing aspects of farmer knowledge were factored into the model. These variables characterised knowledge regarding trees and perceptions of their significance to farm management and rural livelihoods.

These tree management strategies were analysed first using data on the *single* tree cited as most significant to the household and then using an aggregated measure of management vis-à-vis the *three* tree types most significant to the household. The latter set of analyses was preferred for two reasons. First, the explanatory power of the two sets of models was comparable, suggesting that the aggregation rules employed were sound. Second, the aggregated data provide a more complete and balanced picture of household knowledge and practice vis-à-vis trees.

For each of the logistic regressions, the study employed stepwise backwards elimination as its model selection criterion to identify the best model for explaining observed patterns of the dependent variable. Independent variables were eliminated if they failed to show statistical significance at 10%. In practice, all such variables were omitted entirely from the analysis one at a time, in reverse order of their statistical significance. This was done due to the problem of missing cases affecting some study variables, as a result of which excluding insignificant variables from the analysis tended to increase the number of cases in the analysis. Following standard practice with logistic regressions, each model's goodness of fit was assessed using the Nagelkerke R^2 statistic.

The different logit models were assessed using different techniques, depending on the nature of the dependent variable. These included binary logistic regression (models 2 - 6), ordinal logistic regression (models 1, 7 and 9), and nominal logistic regression (model 8).

11. Implications of the regression findings

The clear implication of the empirical findings is that integrating local knowledge variables into regression equations can greatly increase their explanatory power under certain circumstances, notably in low-potential agricultural areas faced with a rapidly changing rural context. While integrating conventional knowledge proxy variables and other 'outside influence' variables was also significant in some cases, such variables were not found to be nearly as significant as the knowledge variables. Indeed, as highlighted in Table 5, the explanatory power of the logit regressions incorporating only resource and outside influence variables was generally doubled by the incorporation of knowledge variables.

Household knowledge was broadly defined to include recognition and implicit valuation of diverse economically relevant aspects of farm trees. These aspects include tree products such as fruit or construction wood, tree services such as soil fertilisation or serving as a windbreak, and tree costs stemming from harm to either cropping or livestock. Such aspects of household knowledge were found to be significant determinants of the tree management models analysed, yet some were much more consistently significant to the models than others, as seen in Table 4. Perceptions of tree products were found to be particularly significant determinants of tree management practice, while perceptions of harmful impacts on cropping were also key determinants. By comparison, perceptions of environmental services were found to be relatively insignificant.

Although the 'outside influence' variables were also sometimes significant, as a group they were less powerful than local knowledge variables at explaining tree management practice. Insofar as Swahili language skills serve as a proxy not only for education but also for contact with extensionists and development projects, the minimal significance of this variable suggests that such contacts do not strongly impact management decisions. By contrast, the high significance of the HASHI (i.e., contact with agroforestry project) variable suggests that institutional contacts can be significant.

The generally higher explanatory power of the local knowledge variables relative to outside influence variables may be attributable to the nature of the technologies in question, namely low-status technologies with gradual payback profiles whose principal function is supporting production for home consumption. With such technologies − which may be critically important in low-potential areas − local knowledge variables appear to be more significant determinants of technology adoption than factors such as schooling or extension contact.

Another implication is that tree cultivation is not typically resource-constrained in a fundamental sense, since it may require only marginal inputs of available resources. Notably, it does not appear to be constrained by labour, in contradiction to existing theory. The key question, therefore, may be whether tree cultivation is seen by households as an advantageous use of limited household resources, as determined by both tangible resource constraints and intangible factors such as farmer knowledge.

In sum, the findings show that tree management in Shinyanga District is complex, and that considering key resource constraints and outside influence variables facing households explains only a relatively modest proportion of the observed variation in tree management practice. A significant proportion of the unexplained variation may be accounted for by integrating knowledge variables into the analysis. Thus, the data broadly support the hypothesis that local knowledge variables may be key determinants of tree management practice under certain conditions. Implications include that local knowledge may fail to reflect the incentives faced by households, and that this knowledge may affect tree management practice independently of resource effects.

12. Associations analysis

A second analysis sought to further elucidate households' thinking using species-specific knowledge data. Its goal was to identify which tangible and intangible characteristics of farm households show statistical associations with observed patterns of species-specific tree knowledge, in the interest of suggesting which types of households fall into distinct knowledge categories. Because it involves only pairwise correlations among factors unguided by specific hypotheses, this discussion is exploratory. Yet it highlights promising future angles of inquiry, both for examining causality of distinct knowledge outcomes and for suggesting possible means of addressing knowledge gaps.

Figure 2 summarises these exploratory pairwise correlations. The resulting analysis presents a suggestive anatomy of distinct knowledge categories based on these statistical findings. The categories as defined are strictly empirical, following from the associations found. Various associations were left out of this summary analysis due to their not showing clear linkages with other associations. Yet many associations of species-specific tree knowledge with 'intangible' associative variables fell neatly into one category or another[5]. This analysis defines three broad categories of farmer thinking vis-à-vis trees and farm management.

Category one may be characterised as disinterest in trees and a narrow view of their role in the farm system. Households in this category emphasise low-value tree products and neglect potential feedback loops with other farm components. They take a passive view of replenishing soil fertility and securing tree products, and only make minimal comments about the environmental benefits of off-farm trees.

Category two may be characterised as viewing trees as the source of high-value tree products. Households in this category emphasise the capacity of trees to provide such products while de-emphasising their capacity to provide agricultural support services, notably soil fertilisation. These households also emphasise harmful impacts of trees on crops, whether via soil effects or shading. Their emphasis on crop rotation and micro-irrigation suggests that such households show a degree of agency vis-à-vis responding to pressure on resources, although this agency does not extend to integrating trees into the farming system.

Category three may be characterised as a comprehensive view of trees, including harnessing positive feedback loops. Households in this category are particularly likely to cite agricultural support services such as soil fertilisation, yet may also emphasise diverse tree products. Their tendency to cultivate leguminous crops suggests an appreciation of the need to respond to pressure on resources, while their tendency to cultivate vegetables suggests dynamism. Their greater tendency to use purchased inputs in their farming system suggests that these households may be comparatively well-off.

13. Sustainable livelihood framework diagrams

The four diagrams appearing in Figures 3 – 6 use the sustainable livelihoods framework to illustrate the key linkages and dynamics characterising different farming systems. Three diagrams highlight the three farming systems highlighted above, while the fourth illustrates the case of a household plagued by knowledge failure. The intensive sustainable agriculture diagram may be said to represent cases where neither extensive agriculture nor Green Revolution agriculture is viable, yet where knowledge failure is not a problem, either due to effective adaptation to change or because any knowledge gaps have been addressed. Relative to the present study, the key aspects of each diagram are as follows:

<u>Figure 3</u>: Green Revolution farming systems rely on regular access to purchased agricultural inputs and market opportunities. Natural capital is seen as either insignificant or undesirable, depending on the natural resource in question, and hence is either ignored (i.e., soil organic matter) or actively removed (i.e., farm trees). While LK may be sound, it is not seen as powerful, and GK is seen as a more powerful substitute, holding promise of market-based growth. Yet this farming system also depends upon access to relevant infrastructure, finance and market opportunities.

[5] The resulting findings *do not* imply that all households citing a given factor fell into a particular category, just that there was a clear tendency for such households to do so. Thus, while households citing kitchen waste may show a clear tendency to fall into category one, such households may also fall into other knowledge categories.

Figure 4: In the traditional view, peasant farming systems rely on the ongoing viability and natural abundance of natural resources. Natural capital tends to be seen as abundant and essentially ‘free’, so conservation or investment in natural capital are not priorities. At most, these generally entail ‘passive’ management of useful natural resources, such as retaining useful species of naturally sprouting farm trees and practicing fallowing. LK is assumed to be sound and to adapt spontaneously to changing circumstances, accurately informing the management of natural resources.

Figure 5: Peasant farming systems plagued by ‘knowledge failure’ still rely on natural resources, but these have become scarce, undermining productivity. Despite this, households’ knowledge and management of natural resources resemble those in the ‘traditional view’ diagram above. That is, LK has failed to adapt spontaneously to changing circumstances, and households neglect incentives favouring conservation of and investment in farm-based natural capital.

Figure 6: Peasant farming systems in which ‘knowledge failure’ has been addressed likewise rely on natural resources. Yet here the household conserves and/or invests in farm-based natural capital to sustain the basis of the system. Thus, LK vis-à-vis natural resources has shifted, and households recognise the need to actively increase natural capital stocks given growing environmental scarcity coupled with difficulty accessing purchased agricultural inputs.

The management question raised is what happens if the inputs on which the first two farming systems depend are no longer available. If households continue relying on the farm for their livelihood, their two options are ‘belt-tightening’ to cope with stagnant production (Figure 5) and shifting their resource management strategy to actively compensate for growing environmental scarcity (Figure 6). Alternatively, those with access to such opportunities may rely increasingly on off-farm labour or remittances, or may seek new agricultural opportunities via out-migration from the area.

14. Significance of paper

The present paper posits and substantiates the ‘knowledge failure’ concept. As such, it (i) helps explain why natural resources may be ‘mined’ and regenerative technologies neglected, (ii), elucidates a determinant of whether the linkage between rural livelihoods and local environments forms a ‘vicious’ or ‘virtuous’ circle, (iii) highlights concrete measures to help harness the potential of these technologies, notably via targeted investments in human capital vis-à-vis natural capital.

It also suggests a potentially central role for environmental economics in rural development and poverty reduction. This follows because technology adoption by peasant households is partly a valuation issue in cases where ‘implicit valuation’ falls short. Yet this role would imply environmental economics in a distinct form to fit the distinct case represented by peasant economies. Notably, it would need to emphasise both incentives and knowledge as potential constraints to harnessing environmental values.

If used to help reform information provision to peasant communities, this work could have a major impact on poverty. By addressing identified knowledge gaps, tailored information provision efforts could redress key constraints on households’ capacity to meet their livelihood objectives. Specifically, such efforts promise to increase farm-based stocks of natural capital. In areas where natural capital is the limiting asset, the resulting benefits may include raising the marginal productivity of both land and labour while also increasing the resilience and sustainability of production. Potentially, this could allow households to escape from the ‘vicious circle’ wherein resource degradation and agricultural stagnation mutually reinforce one another. Conversely, knowledge failure left unaddressed could impair both endogenous adaptation to changing circumstances and farmer input into development initiatives via the participatory approach.

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Table 1: In peasant economies, NRs play a distinct role, face distinct threats

	Case of 'modern' economies	Case of peasant economies
Basis of rural economy	Industrialised agriculture, ranching, logging	Peasant farming and resource extraction
Relation to markets	Commercial production, with fully developed input and output markets	Semi-subsistence production, output largely for home consumption
Key production inputs	Capital, high-potential agricultural land	Labour, low potential agricultural land
Key environmental concerns	Pollution, waste disposal, depletion of global natural resource stocks	Degrading or depleting stocks of local yet critical natural resources such as soils, pastures, woodlands, waterways
Economic significance of natural resources	Provide luxury goods & services to address longer-term concerns of the better-off, e.g., wild biodiversity, clean air and water	Provide goods & services to address basic needs of the poor, e.g., food, fuel. May also be of use to others, e.g. timber, parks
Key economic actors	Government and firms	Rural households, though government and firms may also be significant

Figure 1

Responsiveness of NRM to emerging NR scarcity depends on permeability of knowledge 'filter'

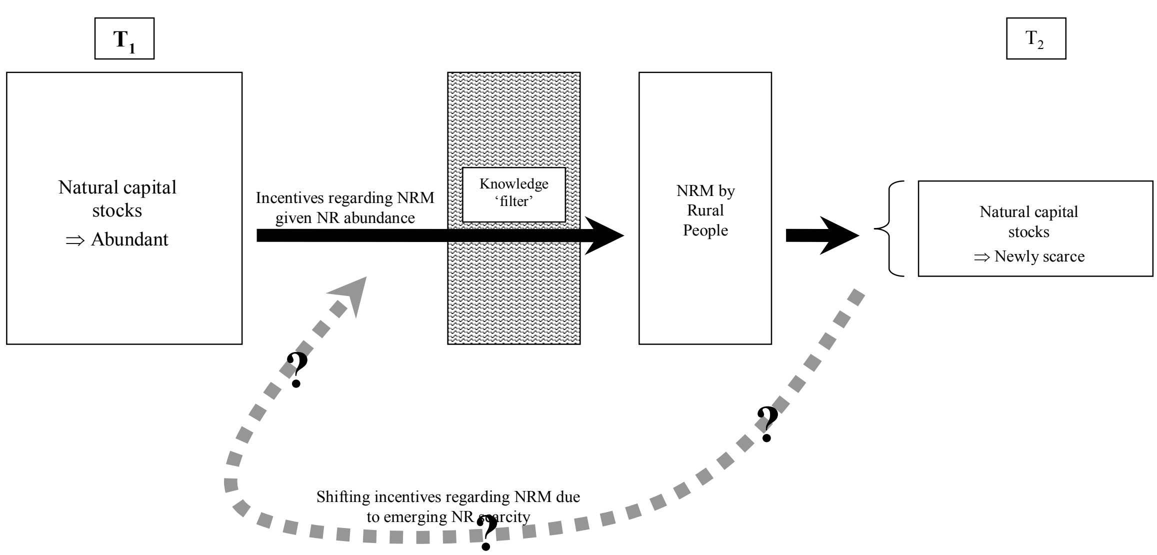

Table 2
Reasons why the LK informing NRM may be problematic given emerging NR scarcity

⇒ *Demands on LK are great since NRM is complex*

Context-dependent behaviour of NRs	Renewable NRs reproduce themselves spontaneously via natural regeneration under favourable conditions yet fail to do so where use pressures are intense, possibly becoming degraded or scarce. Also, reproduction rate may change with stock size.
Radical changes in optimal NRM	Where formerly abundant NRs become scarce, optimal NRM may involve a radical transition from 'passive' to 'active' management, or from managed exploitation to actively facilitating regenerative processes, e.g., tree cultivation
Missing markets	Given their historical abundance and tendency to reproduce themselves spontaneously, NRs are not generally priced, obliging local managers to estimate their value via 'implicit valuation', i.e., in their heads without clipboards or calculators.
Density-dependence of NR values	In areas where NRs are abundant they are of low value, since any benefits are virtually free while any costs may be significant, yet these same NRs may become valuable when scarce, since their costs are few and benefits rare.
Complex role of NRs & regenerative practices	Regenerative practices typically provide diverse goods and services while also imposing costs, all of which display gradual shifts over time. Different NRs may interact either symbiotically or competitively.
Factors affecting context of NRM	Besides growing human and livestock populations, broader factors complicating local NRM decisions include migrations of people or herds, fluctuating market prices, evolving local institutions and government policy, and climate change.

⇒ *Responsiveness of LK to change may be problematic*

Pertinence of historical experience	Past experience may be a poor guide to informing current NRM decisions where the rural context has changed fundamentally over time. Notably, it may encourage rural people to view local NRs as 'free gifts of nature'.
Socio-cultural embedding	Households may hold settled views about how things are done in the local context that are not typically held up to critical scrutiny and that may be embedded in local mythology and/or inflexible community institutions.
Provision of inappropriate knowledge	Rural people may adopt views ill-suited to their circumstances based on the authority of powerful outsiders, while exposure to forceful assertions may shake their confidence in their own judgement.
Adverse reactions against coercive policies	Examples include colonial soil conservation policy emphasising terracing, which led to anti-conservationist views among peasants, and recent policies advocating de-stocking or imposing fines for harvesting products from nature reserves

Table 3 Tree species cited by at least 10% of survey households

Botanical name (**exotic fruit tree) (*indigenous fruittree)	Common name (English)	Common name (Swahili)	Total households citing tree	% citing it as most significant tree	% citing it among most significant trees
Acacia nilotica	Prickly acacia	*Mihale*	122	21	35
Acacia tortilis	Umbrella thorn	*Mgunga*	101	13	29
Mangifera indica**	Mango	*Maembe*	61	10	17
Tamarindus indica*	Tamarind	*Mkwaju*	55	4	16
Cassia siamea**	Sweet orange	*Mchongoma*	51	5	14
Acacia drepanolobium	-	*Malula*	49	2	14
Acacia polyacantha	White thorn	*Nguu*	47	2	14
Balanites aegyptica*	Desert date	*Miyuguyu*	39	2	11
Azadiracta indica	Neem	*Mwarubaini*	36	4	10
Albizia harveyi	Rain tree	*Mpogolo*	35	5	10
Leucaena leucocephala	Lusina	*Lusina*	35	4	11

Table 4: Factors found to be significant in tree management models

Factors	Logit 1	Logit 2	Logit 3	Logit 4	Logit 5	Logit 6	Logit 7	Logit 8	Logit 9	Total
FARMSIZE	+**	–		+**	–**		–**	Y**	–*	7
TENURE	+**				+*					2
SOILTYPE						+				1
LAB.IN		+**	–*	–			+**	Y*	+*	6
LAB.OUT	–*	+*	–				+*			4
NFI.MAJOR	+*						+			2
LIVESTCK		+	–**		+**		+*	Y	+	6
INCIDENCE		–**		–				Y	+*	4
RELIGION	+**		–**	–*	+		+**	Y**	+*	7
SWAHILI	–									1
RADIO		+*			+**		+**	Y*	+	5
HASHI	+	+**		–**			+**	Y**	+**	6
KEYFODD				+**	–*		–**	Y**	–**	5
KEYMEDS				–*		+**	+*	Y**	+	5
KEYCWOOD				–*		+**	+**	Y*	+**	5
KEYOTHER	+*									1
FERTILISE					–*			Y*		2
HARMSOIL	+*	–			–**	+*		Y**		5
HARMSHADE	+**	+**			+**					3
MAKERAIN	–	–					–			3
OTH.ENVTL		+								1

Source: Shinyanga District household survey, 2000

Table 5 Explanatory power (i.e., R^2) of different versions of the logit models

⇒ Column 1 includes only resource variables such as land, labour and capital

⇒ Column 2 also includes GK variables such as schooling and extension contact

⇒ Column 3 also includes LK variables vis-à-vis tree characteristics

Regression Model	RVs Only	Add GKVs	Add LKVs	Multiple gain
L1, Total number of farm trees	11.3%	14.5%	26.2%	1.8
L2, Sales of tree products	12.1	17.5	21.5	1.2
L3, Neither retained nor cultivated farm trees	11.5	15.5	No change	0.0
L4, Retained farm trees but did not cultivate them	8.6	15.5	26.7	1.7
L5, Cultivated exotic fruit trees	8.1	No change	30.4	3.8
L6, Planted & watered indig. fruit or non-fruit trees	1.8	No change	12.9	7.2
L7, Tree management intensity	8.6	12.0	22.6	1.9
L8, Type of tree cultivated	14.8	21.0	46.6	2.2
L9, Location of tree cultivation	5.8	12.8	20.8	1.6

Figure 2 Diagram of the associations analysis

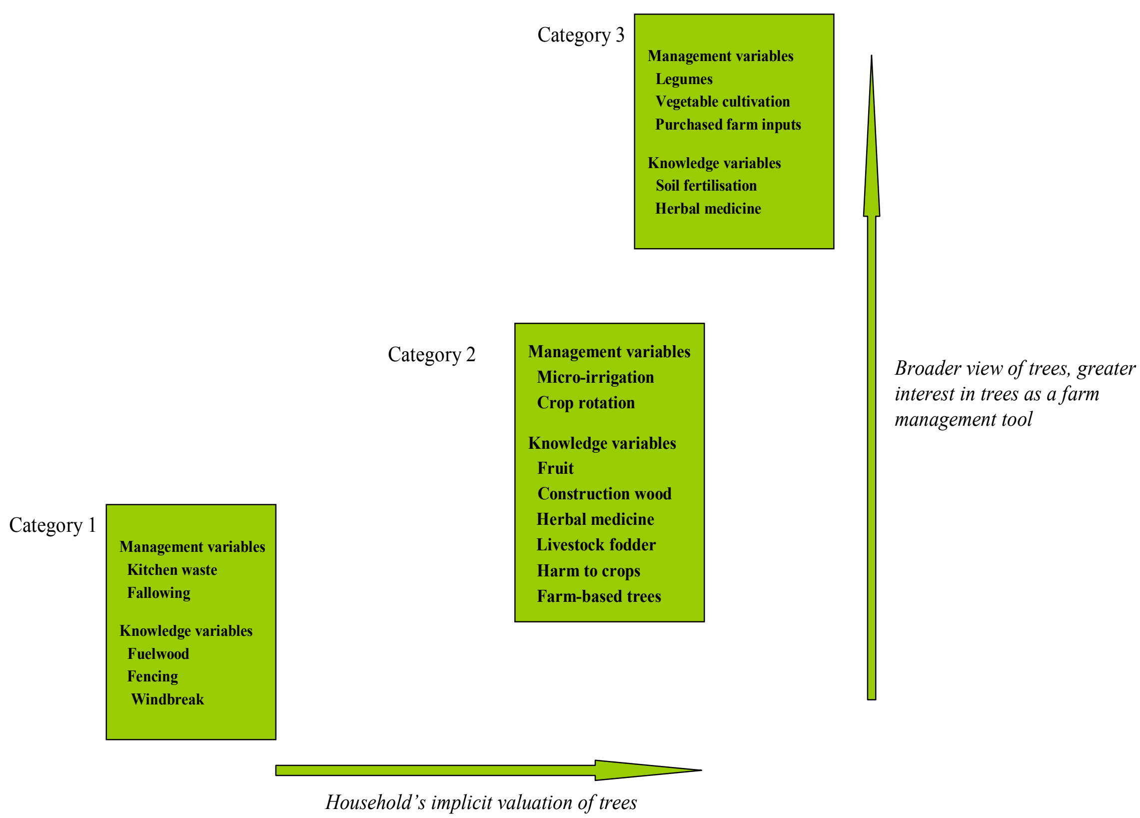

Figure 3 Green Revolution agriculture

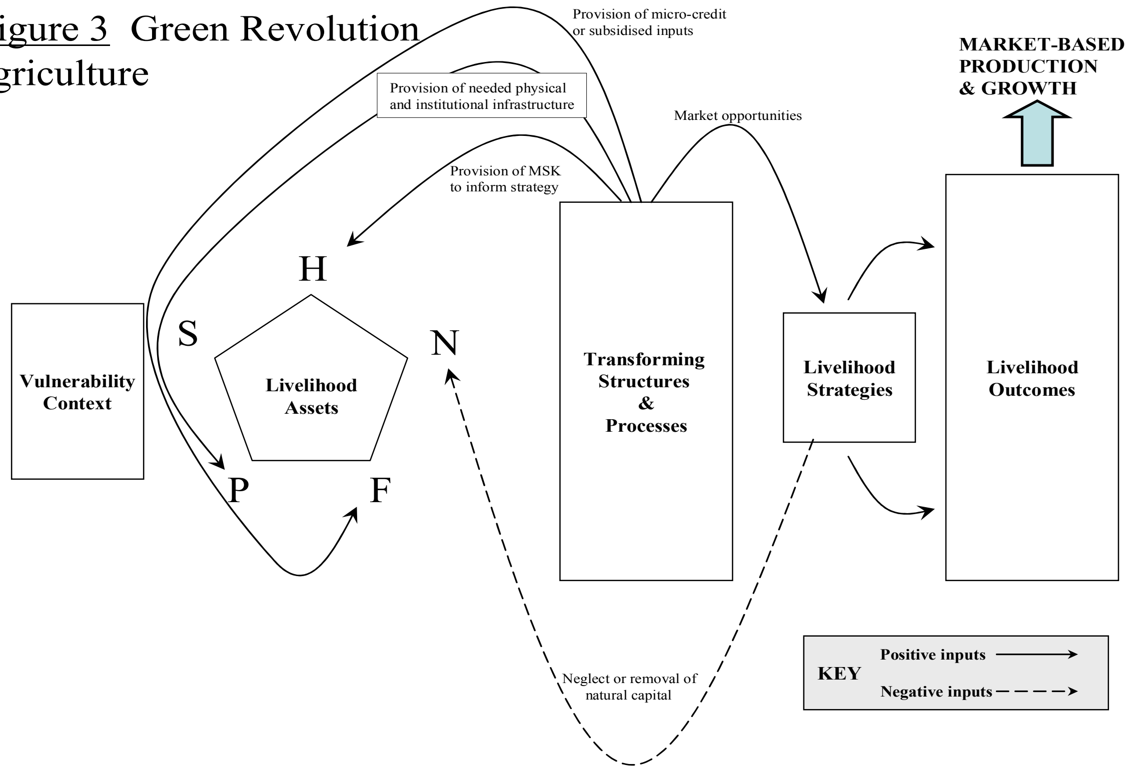

Figure 4 Traditional view of peasant farming

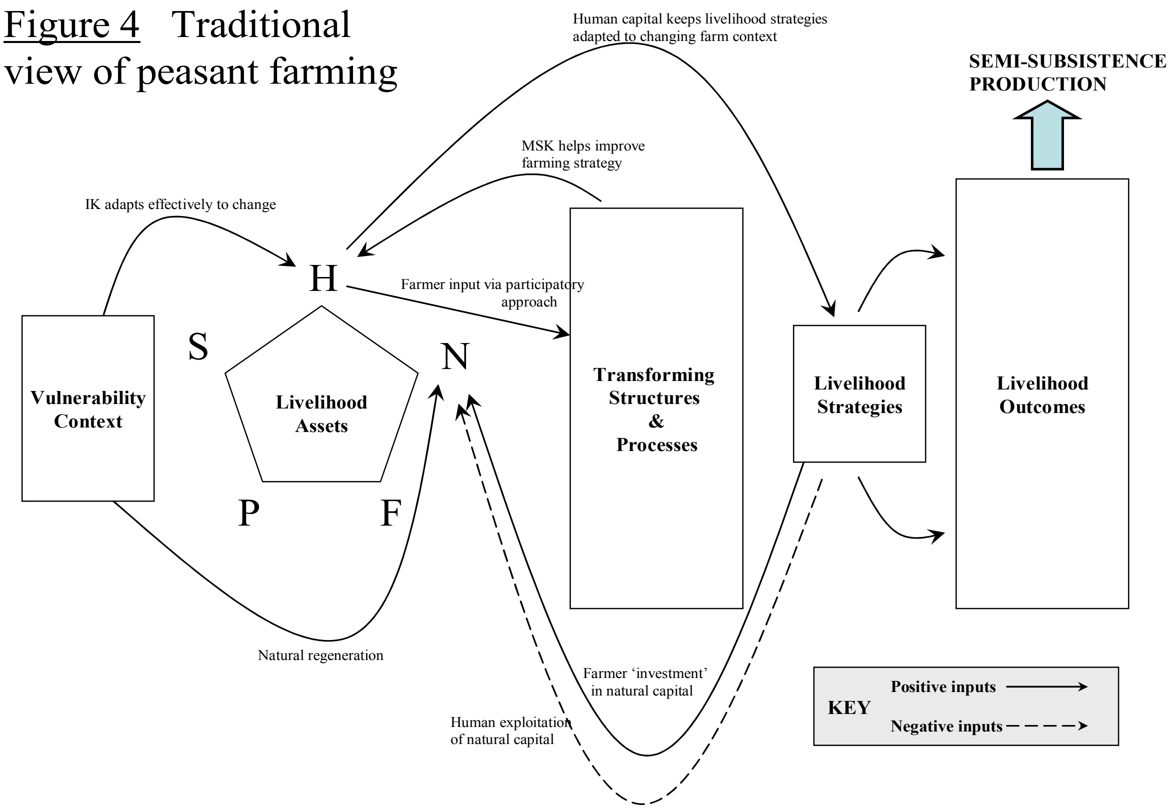

Figure 5 Peasant farming given 'knowledge failure'

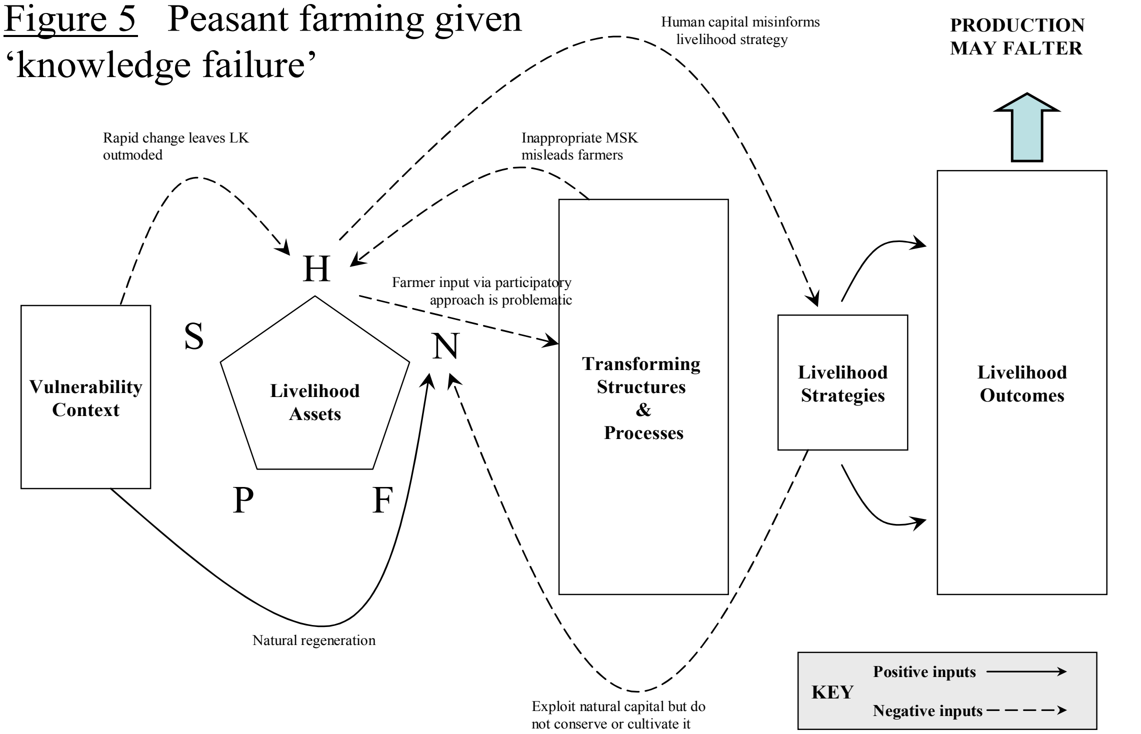

Figure 6 Addressing 'knowledge failure'