SP-PRCA WORKING PAPER NO. 1

PROPERTY RIGHTS, COLLECTIVE ACTION AND TECHNOLOGIES FOR NATURAL RESOURCE MANAGEMENT: A CONCEPTUAL FRAMEWORK

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IFPRI

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IFPRI

October 1998

ABSTRACT

This paper explores how institutions of property rights and collective action play a particularly important role in the application of technologies for agriculture and natural resource management. Those technologies with long time frames tend to require tenure security to provide sufficient incentives to adopt, while those that operate on a large spatial scale will require collective action to coordinate, either across individual private property or in common property regimes. In contrast to many crop technologies like high-yielding variety seeds or fertilizers, natural resource management technologies like agroforestry, watershed management, irrigation, or fisheries tend to embody greater and more varying temporal and spatial dimensions. Whereas the literature addressing constraints and enabling factors for rural technology adoption have largely focused on their direct effects on crop technologies, the conceptual framework presented here shows how property rights and collective action interact with many other constraints to technology development (such as wealth, information, risk, or labor availability). The paper further explores how the structure of property rights and collective action shape the efficiency, equity and environmental sustainability of technological outcomes, thereby enriching our understanding of different technologies' contributions to poverty alleviation.

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1. INTRODUCTION

The technologies people use play a fundamental role in shaping the efficiency, equity, and environmental sustainability of natural resource management. This has been the reason for substantial investments in research to improve agricultural technologies, from new crop varieties to natural resource management practices. However, improved agricultural and natural resource technologies are of little value unless they are judged to be appropriate by farmers and subsequently adopted. There are many factors constraining farmers' technology choices, but the lack of secure property rights has been commonly identified as an important barrier to adoption, particularly for longer-term investments in things like tree crops and improvements to natural resources. For technologies and natural resource management practices that require that farmers make joint decisions and cooperate in their implementation, inadequate and ineffective institutions for managing collective activity can be a constraint to adoption. Property rights and collective action (PRCA) are also important in determining who benefits from productivity increases (equity), both directly by determining who can reap the benefits of improvements in

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factor productivity, and indirectly through their effects on land markets, access to credit and the like.

This paper seeks to examine an extensive and growing literature on the links between PRCA and farmers' decisions about use of new technologies, including how property rights and collective action interact with other factors to either constrain or enable adoption. It further explores how PRCA condition the way technological changes translate into productivity increases, reductions in poverty, and environmental outcomes. Technology is used generally in this paper to include natural resource management practices as well as production processes and methods.

The following section of this paper reviews evidence on the major influences on technology choices, including the direct effects of PRCA. Following that, we develop a framework for understanding how property rights and collective action institutions[1] influence even the other constraints on technology choices, such as information, risk, or credit. While building on existing research, this framework highlights gaps in our present understanding, and can provide a basis for framing future empirical research. The next section deals with the effects of technologies on institutional change in PRCA, followed by a discussion of the impact on productivity, poverty and the environment. We conclude by examining how an understanding of these relationships can better inform policy decisions about the design of agricultural research and development, and reforms to PRCA institutions to enhance the use and impact of improved technologies.

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[1] Institutions are defined as "the rules of the game in a society or, more formally, are the humanly devised constraints that shape human interaction (North 1990:3)." Following this definition, both property rights and regularized collective action can be considered institutions.

2. FACTORS INFLUENCING TECHNOLOGY CHOICES

The Green Revolution brought forth technologies which led to substantial productivity increases. However, the crop varieties, agrochemicals, and irrigation technologies in the Green Revolution package were not evenly adopted by all types of farmers. Questions of why differences remained between regions, and even between farms within an area, sparked a large body of theoretical and empirical literature on factors which constrain and those which enable technology adoption. Given the orientation of the Green Revolution toward high-yielding variety (HYV) seed and use of improved inorganic fertilizers, emphasis was laid narrowly on constraints to crop production technology, rather than natural resource management (NRM). Nevertheless, these factors and the logic which identifies them as constraints provide a foundation for understanding constraints on other types of technologies, including the use of improved natural resource management practices, and their interaction with property rights and collective action. This section provides a brief overview of what those factors are and the rationale underscoring their effect on the adoption of different technologies, particularly new technologies introduced to increase production or improve the condition of the natural resources.[2]

INFRASTRUCTURE AND INFORMATION

Access is a critical dimension of technology choices. Unless the appropriate physical, economic, and information infrastructure is in place, farmers may be unable to acquire technological inputs or market their output. Whereas roads, electricity, water supplies,

[2] Although in much of the literature, the term ‘technology adoption’ has referred to new or ‘improved’ technologies developed by national or international research stations or introduced through technologies transfer programs, in this paper ‘adoption’ also includes those technologies or practices where farmers themselves have played a considerable role in technology innovation.

availability of improved seeds and other key inputs, and access to market outlets may be obvious considerations for whether a technology is adopted or not, less obvious may be barriers to the diffusion of information. Farmers must know about the availability of new technologies, and this knowledge must extend to knowledge about the returns from adoption, which in a risky world requires judgements about alternative possible outcomes of yields and profits. Full information about profitability and risk is rarely available for new technologies, simply because they are new. Consequently, farmers' perceptions of risk may dominate the adoption decision in the early years, particularly if the early years prove to be unfavorable.

If farmers form their risk perceptions in a rational way, then with the passage of enough time, their perceptions will tend to move from subjective to objective risk assessments based on knowledge of the interactions between technologies and their environment (O'Mara 1983). But in the early years, farmers may have exaggerated perceptions of the risks involved with new technology, making them prefer those with which they have more experience. Effective extension services can accelerate the spread of knowledge about the profitability and risks associated with new technologies. Farmers are also quite efficient in learning from each other, and at experimenting on their own farms.

ENVIRONMENTAL AND PRICE RISK

Farmers are generally averse to risk, although there is considerable variation in their individual behavioral patterns (Anderson, Dillon, and Hardaker 1977). If a new technology is clearly superior to an established technology in the sense that the return will be greater no matter what happens to weather, prices, etc., then risk aversion is not likely to deter farmers from using it (Anderson 1974). But if the new technology is not superior under all possible eventualities, then differences in risk attitudes can play a role, even when perceptions about the riskiness of the new technology are correct.

If farmers are risk averse, then they should be more reluctant to adopt risky new technologies even when these are more profitable on average, but more receptive to risk-reducing technologies such as irrigation or more stable crop varieties. Surprisingly, the empirical evidence on the importance of risk in technology choices is not conclusive (Hazell and Anderson 1984). Much seems to depend on household livelihood strategies, which are conditioned by wealth and whether farmers have efficient options for reducing their exposure to risk, and/or to coping with losses when they arise (Chambers and Leach 1989; Scherr 1995). Risk reducing options may include income and crop diversification, inter-cropping, and plot scattering; risk coping strategies may include use of savings or credit, storage, family support networks, and asset markets. Where these options are available, the amount of additional risk associated with alternative crop technologies or production techniques may be too small for risk to play an important role in these decisions. Risk is doubtless more important though when efficient risk management options are limited, as may be the case with many small scale farmers, or when farmers have to choose among "lumpy" technologies (Feder 1982; Zeller, et al. 1997; Bell 1972), such as the purchase of machines or livestock, or sizeable investments in resource improvements such as irrigation, terraces, or drainage.

WEALTH AND CREDIT

Wealth expands a household's options to acquire and use technologies, especially those that require the outlay of considerable resources. Lack of wealth need not be a constraint to technology adoption for other low asset households, provided financial markets are available to provide necessary financing arrangements. However, a sizeable body of literature points to the lack of access to credit and savings services for farmers in many rural areas, limiting their ability to purchase needed technological inputs (Lipton 1976; Jehangir 1998; Bhalla 1979; Wills 1972; Feder, Just, and Zilberman 1982; Feder 1980; Subbarao 1979; Hazell and Anderson 1984).

Whereas transaction costs of lending play a role in making small loans in more remote areas unviable, the credit that is available is often biased against small farmers and women because of their lack of collateral and perceived higher default risk. In response to this, many countries implemented subsidized agricultural credit programs, often tied to purchases of new technology. While these approaches were helpful to the uptake of Green Revolution technologies, most of these programs proved financially unsustainable, and often failed to reach small farmers and women. The contraction of subsidized and publicly funded credit schemes in recent years has led to new approaches to rural finance, including development and strengthening of local institutions for micro credit and mobilization of rural savings. Zeller et al. (1997) provide some recent evidence that these approaches can facilitate purchases of new technology, especially amongst small farmers.

LABOR

Labor bottlenecks can also be a significant constraint to the use of some kinds of technologies (Delgado and McIntire 1982; Feder, Just, and Zilberman 1982; Kirk 1988; Harriss 1972; Helleiner 1975). High yielding crop varieties not only add to total labor requirements, but they often exacerbate seasonal peaks in labor requirements. Peaks typically occur at planting, weeding and harvest times. If the new varieties have a shorter growing season, and permit additional multiple cropping, there may be consequent overlapping of the harvesting and planting of successive crops with very sharp increases in seasonal labor requirements. Unless local labor markets are elastic, increases in demand for labor raises seasonal wage rates which can quickly dampen the profitability of new technologies, particularly for farms which cannot get by with family labor alone. Even when wage rates do not rise, supervision costs make hired labor relatively more expensive than family labor because work effort, and therefore labor productivity, tends to be lower for the former. Changing to new techniques may then depend on complimentary and expensive investment in farm mechanization, which can be a particular hurdle for small farms because of the lumpiness of the required investment and the need for a minimum farm size to spread the cost. Efficient machinery rental markets can help neutralize these constraints, but transaction costs and excess demand in peak periods can still work against small farms. Even when family labor is not constraining for small farms, women's available labor supply may be quite limited due to many competing demands for their labor, thereby leaving them little time to manage new technologies.

Investments in improving natural resources (for example, construction of terraces, irrigation, water catchment areas, drainage, and regular composting) can be particularly labor demanding, and may be too expensive to undertake in communities with limited access to labor. However, if many of these investments are carried out in the off-season where they do not compete directly with labor for agriculture, opportunities costs for labor may be lower. The literature on induced innovation hypotheses argues that many of these labor intensive investments will only be undertaken when population density reaches critical levels and land becomes scarce relative to labor (Boserup 1981; Hayami and Ruttan 1985). Commercialization of agriculture can have a similar affect, raising the value of land and hence also increasing the returns to investments that improve its productivity.

PRICE POLICY

The profitability of new technologies is affected by input and output prices, both of which are often influenced by government policies in developing countries. As such, policies that discriminate against agriculture have worked against the uptake of capital or cash-intensive technologies, although more recent devaluation and market liberalization policies have in many cases improved relative prices for traded agricultural goods and, therefore, induced adoption of technologies associated with them. However, these changes have also been associated with increased price volatility for agricultural produce and the removal of many input subsidies, such as credit, fertilizers, and irrigation water, so the net effect on farm level profitability can be quite mixed.

Another price related issue is that as more and more farmers adopt a yield improving technology, the increase in aggregate output can act to depress the market price (Alston and Martin 1992; Bhagwati 1958; Carter 1985). This effect will be greater the more inelastic the demand curve of the international market. If the new technology is clearly superior and acts to reduce average costs per unit of output by a greater margin than it reduces prices, then it may still be attractive.

OTHER CONDITIONING FACTORS

Technologies may be unsuitable beyond the bounds of certain physical, socioeconomic, cultural and political environments. Agroecological conditions have precluded the use of HYV varieties in areas with low rainfall (and insufficient irrigation facilities), unfavorable microclimates, and poor soils (Perrin and Winkelmann 1976; Gerhart 1975; Freebairn 1995).

Likewise, use of ox-plow cultivation or grazing technologies is constrained in areas with very hilly terrain, or in tsetse infested areas (Kumar 1994; Erenstein and Cadena 1997). However, evaluating the appropriateness of a technology or package of technologies goes well beyond its technical characteristics. Even when these attributes appear promising, the ‘social bias’ of a technology arising from institutions and power structures can preclude adoption or the positive outcomes expected from its adoption (Grabowski 1990).

In some regions of Africa and Asia, cultural restrictions prevent women from planting trees such that they are unable to participate in many agroforestry technologies (Neef and Heidhues 1994; Fortmann and Rocheleau 1985). Similarly, legal restrictions may impede use of certain technologies. Given that many such restrictions are linked to property rights, discussion of them will be reserved for a later section.

PROPERTY RIGHTS

Property rights can be defined as “*the capacity to call upon the collective to stand behind one’s claim to a benefit stream* (Bromley 1991:15, emphasis in original).” As such, they are recognized as an important factor shaping the use of different technologies. If people do not have the confidence that they will benefit from investments in technologies, they are less likely to adopt the technologies. Although there is a wide variety of property rights arrangements, several aspects have received particular attention in the literature on technology adoption and natural resource management, notably the effects of landlord-tenant relationships (completeness of rights), and tenure security.

Empirical studies of landlord-tenant arrangements on incentives to adopt yield-enhancing technologies have argued that the expected gains accrued from implementing a particular technology act as disincentives to adopt, either by the tenants or the landlords themselves due to increased risk born by the tenant and the potential for weakening the lucrative patron-client relationship from the perspective of the landlord (Bahduri 1973; Scandizzo 1979). Other literature argues that these arrangements are not constraints themselves, but that other reasons, such as poor terms of trade and information assymetries, prevail (de Janvry 1979; Ghose and Saith 1976). Grabowski (1990) maintains that the high cost of negotiating tenancy and fixed-rent contracts will induce landlords to adopt mechanized agricultural processes in the face of technological change while Bardhan (1979) finds a difference in technology's impact on tenure arrangements, depending on whether it is labor-intensive or land-augmenting.

Most of the literature linking property rights with technology adoption has focused on the role of tenure security in shaping farmers' decisions to invest in agriculture, with empirical studies demonstrating mixed conclusions concerning its importance (Bruce 1993; Roth, Cochrane, and Kisamba-Mugerwa 1993; Place and Hazell 1993; Roth, Wiebe, and Lawry 1992; Barrows and Roth). Where tenure security is defined in terms of bundles of transfer rights or possession of title, the correlation between security and investment tends to be weaker. Nevertheless, substantial theoretical literature advocates privatization of land based on the premise that farmers' incentives to invest in technologies is inhibited by weak tenure security arising from indigenous property rights institutions and by lack of land titles hindering their capacity to obtain credit to make investments (Demsetz 1967; Johnson 1972; Feder and Noronha 1987). Since then, however, a body of empirical evidence has emerged which casts considerable doubt on the linkage between land title and agricultural investment, indicating that land titling is unlikely to induce enhanced tenure security (Besley 1995; Place and Hazell 1993).

How tenure security is defined has played a significant role in shaping policy outcomes. The Swynnerton Plan (1954) emerging out of colonial Kenya equated tenure security with ownership and title to land as practiced by Western countries. Indeed, much of the policy prescriptions for Africa and other developing countries that emerged in the next two decades followed suit in arguing for the need to replace community-based land tenure institutions with freehold tenure backed by formal titles (Harrison 1987; Dorner 1972; Feder et al. 1988; Feder and Onchan 1987). Subsequent research has revealed that title and privatization of land ownership are not always necessary to ensure tenure security and in fact may in some cases weaken it (Bruce 1993; Place and Hazell 1993; Shipton 1988; Roth, Unruh, and Barrows 1994). This result stems from the strength and effectiveness of indigenous property rights institutions that still exist in much of Africa, often superceding national land laws in the eyes of local people. For example, in Benin, Manyong and Houndekon (1997) found that although plots were not formally registered, divided inheritance, purchasing, and gift modes of acquisition provided enough long-term security to encourage the adoption of soil-improving technology. Likewise, regression results obtained by Ngaido et al (1997) showed that farmers planted improved varieties more on rented land than on owned fields, contrary to expected outcomes. To understand possible rationales for these outcomes, it is useful to explore some of the definitions of tenure security which have emerged in the recent literature.

Definitions provided by Place, Roth, and Hazell (1994) and Roth, Wiebe, and Lawry (1993) stress that the necessary components of tenure security include excludability, duration, assurance and robustness. Excludability allows those with rights to exclude those without rights to a particular factor such as land. Duration refers to the temporal extent of one's rights. To have secure tenure, one must possess a sufficient time horizon to reap the benefits of one's investments. An institutional framework capable of enforcing an individual's rights to land provides the assurance component, while robustness refers to the number and strength of the bundle of rights an individual possesses.

Indigenous property rights institutions have often proven effective in recognizing and enforcing secure property rights for community members, and where these institutions persist, a title does little to strengthen the land rights of community members (Ensminger 1997). In contrast to the conventional wisdom, Smucker, White, and Bannister (1997) report that in Haiti local tenure systems are a source of protection against the insecurity that comes from involvement with formal state tenure systems, which often bring a threat of urban elites taking land. Where indigenous local systems have broken down (either because of internal factors or external threats to the security of tenure, such as outsiders attempting to claim land), registration or land titling may be needed. This may also be true where commercialization has advanced to the point where efficient credit and land markets are needed in which non-community members become important agents (Bruce 1993; Cohen 1980; Noronha 1985). Yet, even where there is demand for land titles, this may stem largely from the ability to reinforce the exclusion and duration elements of security. Recent empirical research from Brazil has shown that it is these factors emanating from possession of land titles which have implications for tree investment and conservation, whereas the ability to sell land with a formal title appears to have little bearing on these decisions (Walker and Wood 1998).

In examining property rights, it is useful to employ the perspective of legal pluralism, recognizing that there is not just one legal system that applies nor a simple division between *de jure* (statutory) and *de facto* (locally practiced) rules, but rather that there are overlapping legal and normative frameworks related to property rights.[3] Not only statutory laws, but also customary and religious laws, and even unwritten local norms may *all* address the rights and responsibilities related to natural resources. Users and potential users can base their claims on the resources on one or another of these legal frameworks, and the overlap and even inconsistencies give scope for negotiation and evolution of property rights. This implies that it is not enough to look only at official statutes, nor at "customary law" in isolation, and that changes in government laws alone do not necessarily change property rights at the local level. This is aptly illustrated in the study by Rae et al. (1997) which attests to the endurance of Bedouin herding institutions in Syria despite a series of shifts in government policy since the 1950s. It further implies that to understand property rights in practice we need to begin not with the formal laws as defined by any system--be it state, religious, or "customary" law, but to begin with individuals, and look at what property rights and other institutions affect them.

Some confusion in empirical findings stems from lack of clarity regarding the scale at which property rights are measured: whether at the plot, farm, or community level. To assess the incentives of individuals or the adoption of technologies that may vary from plot to plot, it is essential to look at the property rights of individual plots, and who they are controlled by. This is especially important where a household may have plots under different types of tenure, and for assessing the effect of gender differences within households, especially in regions like much of sub-Saharan Africa where women and men have separate plots and separate responsibilities for production (Lastarria-Cornhiel 1997). In other cases, the full set of property rights held by a household may indicate the types of livelihood strategies the members can employ, for example, enabling them to try out new technologies on some types of holdings because they have other

[3] Legal pluralism is a central concept in the legal anthropological literature. For more information, see Griffiths (1986); Merry (1988); and Spiertz and Wiber, eds. (1996).

land to meet subsistence needs (for an example of analysis at different levels, see Quisumbing et al. 1998).

Concepts of tenure security have largely been confined to individually or household controlled property rather than common property, which is controlled by one or more groups of individuals or communities. To define tenure security for the users of a common property resource, three dimensions need to be considered. First, does the group or community have secure ownership rights over the collectively managed resource (in the same sense as defined above for individually controlled resources)? Second, is there security of membership in the group to ensure that an individual will have continued use rights to the resource over time? Third, is there an effective local institution to manage and regulate the use of the resource, to assure members that if they abide by the rules, others will also? Many common properties are under increasing pressure today and are degenerating to open access areas. One major reason is population expansion exerting increased competition for resources and producing a growing number of people with group membership claims. Breakdowns in common property management also occur when the ownership rights of the community are challenged by outsiders, including in some cases the state (for example, nationalization of rangelands and forests), and in response to market forces, policy interventions, and other institutional and technological forces which undermine the institutions which have managed the resource (Bromley and Cernea 1989; Jodha 1992; Richards 1997).

COLLECTIVE ACTION

As we move from agricultural technologies that can be employed on individual farms to natural resource management techniques that operate at the landscape level, collective action becomes particularly relevant. The Oxford Dictionary of Sociology (Marshall 1998) defines collective action as: “action taken by a group (either directly or on its behalf through an organisation) in pursuit of members’ perceived shared interests.” Collective action is most visible in community-level efforts to build and maintain local infrastructure for natural resource management. This is seen clearly in farmer-managed irrigation systems (Coward 1986; Leach 1961; Mahendrarajah 1981; Yoder 1994). White and Runge (1994 and 1995) show that people in Haiti often contribute labor for watershed management programs out of a sense of solidarity and reciprocity even if they do not directly benefit economically from land improvements. Drijver, van Wetten, and de Grout (1995) present evidence from the floodplains regions of Lake Chad of village participation in digging canals and constructing protected fish spawning areas, which are owned by groups of villagers. Groups take annual turns refraining from fishing in their spawning area in order to enable increased spawning and augment the fishing population, a sacrifice which is rewarded by a guaranteed percentage of the subsequent communal catch.

Just as the term “property rights” encompasses a number of aspects, so also collective action covers a range of activities. In addition to joint investment in purchase, construction, or maintenance of technologies, such actions as decision-making and implementation of rules to exploit (or refrain from exploiting) a resource; representing the group to outsiders; and mechanisms for sharing information and other resources are especially relevant for agriculture and natural resource management techniques.

A growing body of research (for example, Baland and Platteau 1996; Nugent 1993; Oakerson 1992; Ostrom 1990, 1994; and Rasmussen and Meinzen-Dick 1995; Runge 1986; Uphoff 1986; Wade 1988; White and Runge 1995) outlines conditions for creating and effectively sustaining collective action for managing common property resources. A resource that is to be managed or improved collectively should be accessible to group members to facilitate control and exclusion of outsiders, and small enough for a group to effectively govern (for example, river basins and oceans are possible exceptions). It helps too if use by one member has limited effect on the availability of the resource to other members (low 'subtractability'). Greater social cohesion within the group is facilitated by a smaller number of users, by homogeneity of members in terms of shared values and economic dependence on the resource, and if the net benefits from group membership are substantial and equitably distributed. Birner and Gunaweera's study of *chena* farmers in Sri Lanka attributed their lack of organizational capacity to their large numbers, socio-cultural heterogeneity, lack of access to infrastructure and communication facilities, and aversion to risk (Birner and Gunaweera 1998).

Institutional design is also important. Ostrom (1994) has identified seven design principles for effective local organizations for common property management: (i) there must be a clear definition of the members and the boundaries of the resource to be managed or improved; (ii) there should be a clear set of rules and obligations that are adapted to local conditions; (iii) members should collectively be able to modify those rules to changing circumstances; (iv) there should be adequate monitoring systems in place, with (v) enforceable sanctions, preferably graduated to match the seriousness and context of the offense; (vi) effective mechanisms for conflict resolution; and (vii) the organization, if not empowered or recognized by government authorities, should at least not be challenged or undermined by those authorities.

Where these conditions are not met and collective action needed for resource management is lacking, one of the first questions to ask is why? Are there sufficient incentives for people to participate? The motivation depends not only on quantifiable economic costs and benefits, but also on factors such as time involved and social tensions or gratification from participation. Where there are sufficient incentives but governance mechanisms are lacking, local leadership and/or external community organizers can play an instrumental role in developing local mechanisms (Ensminger 1992). This can be seen as reducing the transaction costs of organizing. But to be sustainable over time, these governance mechanisms need to be institutionalized, that is, not dependent on the actions of a single person.

Lack of boundedness of the resource is more complex. Clear boundaries are important in monitoring and enforcing, and in making sure that those who participate in collective action (either by contributing or refraining from taking too much) will be the ones who benefit from improvements. However, in some cases somewhat "fuzzy" boundaries may be preferred, especially in highly variable contexts, where people recognize that they may need to tap others' resources under crisis conditions (for example, drought), and are therefore willing to allow others to use their resources under similar conditions (Cleaver 1998; McCarthy forthcoming).

LINKAGES BETWEEN PROPERTY RIGHTS AND COLLECTIVE ACTION

In many cases, property rights and collective action are interrelated, especially in natural resource management. This is most clearly seen in common property regimes, which require both clearly defined property rights for the group, and a relatively high degree of collective action within the group. Shared property rights can also reinforce collective action among a group, whereas privatization of a resource or government claims of "ownership" can erode local management institutions (Wade 1988; Coward 1986; Bromley and Cernea 1989). But even private property regimes require collective action to uphold private rights, and managing resources (with or without joint ownership rights) often requires coordination between individuals and households, especially for practices that operate at the landscape level. In their study of land tenure and deforestation in Brazil, Walker and Wood (1998) demonstrate that mutual cooperation to prevent the spread of fire contagions among privately held land holdings constitutes an important element of tenure security and thereby affects investment incentives and environmental protection outcomes.

When assessing the effect of property rights and collective action on technology adoption, it is useful to consider the spatial and temporal dimensions of a particular technology. Irrigation technology or integrated pest management (IPM) technology, for example, require substantial space to operate effectively, and hence are facilitated by collective action to coordinate their adoption (see Swallow et al. 1997b; Ravnborg, de la Cruz, and Guerrero 1998). Likewise the property regimes most appropriate for their management need to take into account this spatial scale. Quiggan (1993) points to joint ownership of harvesting equipment by small farmers as an example of efficiency gains from employing a common property technology to private property resources, which would otherwise impose spatial limitations on adoption.

Because management of common property resources is apt to demand collective action responses to function effectively, the spatial dimensions of a resource and the spatial effects of technologies applied to those resources will also be indicative of whether collective action constitutes a potentially effective management strategy. Every thing else equal, the larger the space occupied by the resource, the more numerous the people dependent on its benefits, and the broader the spatial effects of the technologies applied to it, then the greater the incidence of inter-agent externalities whereby one person's use of a technology has either positive or negative effects on others which are not negotiated through the market. Under these circumstances, the potential for collective action strategies to promote adoption of large-scale technologies and natural resource management practices is generally greater. Collective action institutions may not only facilitate joint resource management, but also include inter-community dialog and conflict resolution. This is not to say that the association, monitoring and enforcement costs of collective action do not increase with space, but that the coordination costs and efficiency losses of managing large scale resources privately will, up to a certain level or size, often overwhelm other costs, making collective action an economically superior alternative, at least in terms of social costs and benefits. Once a threshold size is reached in terms of the transaction costs of sustaining collective action, a role for the state may be warranted. Besides collective action, other means exist for resolving inter-agent externalities, such as tradeable permits, regulations, taxes, and subsidies.

The temporal dimensions of a technology carry implications for tenure security. If property rights, whether individualized or communal, do not offer the resource user sufficient duration to reap the benefits of investment in a particular technology, adoption will not be forthcoming. Here the relationship between timing of costs and the timing and duration of benefits is especially relevant. In cases where technologies require long time horizons to generate returns on investment, tenure security needs to be addressed before meaningful uptake of technologies can be expected. For example, Fortmann, Antinori and Nabane's 1997 study of tenure security and gender differences in tree planting in Zimbabwe found that where women have less security of duration of tenure they are less likely to plant trees.

Figure 1 places several technologies within a spectrum of their relative spatial versus temporal scale. HYV technologies, given their scale neutrality and seasonal nature, are placed at the lower end of the spatial and temporal spectrum. IPM requires a high degree of spatial coordination but with a short-run turnaround. By contrast, terracing technology may be very localized yet investment is continuous and long-term (as demonstrated in Al-Sanabani, Aw-Hassan and Bamatraf's 1997 study from Yemen). Watershed management, irrigation systems, and salinity control require both longer time horizons and coordination among farmers. Finally, basin management incorporates such vast spatial scale that it even extends beyond the realm of strictly local collective action as a feasible option due to the enormity of the transaction costs incurred. Here state intervention or co-management arrangements involving the state and local institutions may offer the best solution.

In applying this framework, it is most useful if the spatial scale is seen relative to normal farm sizes within a given area. A technology serving 100 hectares could be internalized and adopted within a single farm in some areas, or require coordination of hundreds of farmers in other areas. Lynam (1994) notes that moving from agricultural to natural resource management technologies generally expands both the temporal and spatial scale of research and adoption; even technologies which are put into practice at the farm level require widespread adoption to become effective (as exemplified in IITA's program for biological control of the cassava mealybug).

Several of the technologies specified in Figure 1 could be broken down into subgroups to more accurately reflect their spatial and temporal characteristics. The "irrigation" category should distinguish between tubewells serving a single farmer on a few hectares and a large canal system serving thousands of hectares. Within the agroforestry category (see Figure 1A), community nurseries will tend to require much greater degrees of collective action to sustain them while security-enhancing property rights are less important given the short time necessary to derive benefits from the technology. By contrast, agroforestry aimed at production of fuelwood or poles requires an extended duration for production, yet the practice is more individualized and requires much less, if any, coordination beyond the household level. Similarly, while comprehensive watershed management often has a large spatial scale and long time horizon, specific components such as contour plowing can be applied on smaller areas with shorter-term pay-offs.

Viewing technologies in this framework allows more precise identification of whether property rights or (lack of) collective action are likely to be constraining or enabling factors in technology choices. It can also provide guidance for the development and dissemination of technologies that are appropriate for the institutional context. For example, technologies that operate on a landscape scale may be more appropriate where traditions of cooperation are strong while those that require an extended duration to produce benefits may realize greater success where tenures are long-term and reasonably secure, at least for those resources linked to the technology being applied. Conversely, areas where many farmers have insecure tenure call for technologies that have significant short-term returns.

3. INDIRECT EFFECTS ON TECHNOLOGY ADOPTION

The previous section has specified a number of factors which the literature has identified as having a direct impact on technology choices. Figure 2 provides a conceptual mapping of these direct effects. Here the constraints are grouped into four categories: *physical/technical factors* such as agroclimatic conditions (including risk) or infrastructure, *social and economic factors* including human capital (information), economic risk, social networks, wealth, credit availability, labor patterns, and social norms; *policy and government factors* such as pricing policies or legislation regarding resource use, and *property rights and collective action institutions*. In econometric terms, they can be viewed as a series of explanatory variables with technology adoption (specified as a binary or continuous variable) as the dependent variable:

$$I = f(x_1, ...x_n, PR, CA) \quad (1)$$

where

I = technology adoption, whether individual or collective

x_i= conditioning factors affecting technology adoption, such as risk, access to credit, prices, labor bottlenecks, and access to information and inputs.

PR= property rights measured according to the bundles of rights and the various criteria for tenure security.

CA= A measure of collective action.

However, this model is too simplistic in assuming that each of the explanatory variables is independent of each other. In reality, many of the explanatory variables are themselves conditioned, at least in part, by the prevailing property rights and collective action systems, and these are not considered in the model in Figure 2. A more realistic model which shows the dependence of many (for simplicity, all) of the conventional explanatory variables on PRCA is outlined in Figure 3 and demonstrated by the following relationships:

$$x_i = f(z, PR, CA);\ i = 1 \text{ to } n \quad (2)$$

$$I = f(x_1...x_n, PR, CA) \quad (3)$$

Substituting (2) into (3) gives the reduced form relation:

$$I = f(z, PR, CA) \quad (4)$$

where

z = exogenously generated conditioning factors, such as household and site-specific characteristics.

Figure 3 and the above model illustrates how traditional constraints act on and are acted on by property rights and collective action to influence the decision to adopt. There is a two-way mapping between traditional constraints and PRCA, which subsequently influences choice of technology. An example of the impact of traditional constraints on PRCA might be if population pressures stimulate the emergence of more privatized forms of land tenure, which may in turn reorient technological choices toward smaller-scale technologies that can be better managed by families and individuals. Pender and Scherr (1998) test the effect of population growth and other socioeconomic variables on the likelihood of local organizations and collective action in Honduras, and relate these to intensification through coffee, horticulture, forestry, basic grains, or other enterprises. In the reverse case where PRCA shapes other constraints, forcible sedentarization of pastoral populations may expose them to greater environmental and food security risks, causing them to uptake crop technologies and reduce their stock numbers.

Similarly, technologies and their adoption can stimulate institutional change as in the case where introduction of integrated pest management technologies have fostered increased levels of community and inter-community organization (Ravnborg, de la Cruz, and Guerrero 1998) or in the case of agroforestry technologies strengthening tenure security. The equations below demonstrate not only technologies' impact on institutions, but also how exogenous and endogenous factors, including other institutions, act as causal elements for shaping property rights and collective action.

$$PR = f(y_i, CA, I)$$
$$CA = f(y_i, PR, I) \quad (5)$$

where

y_i = exogenous factors like population growth, community- and region-specific characteristics, and national laws and policies.

The final mapping in Figures 2 and 3 is directed toward the outcomes of efficiency, equity and environmental sustainability, and suggests that PRCA can be important in determining these outcomes. We shall consider these linkages in Section 5. These factors then feed back on the environmental and institutional conditions, for example, through population growth or changes in the physical condition of the resource. With the framework of Figure 3 in mind, this section will explore some of the important inter-dependencies that have emerged in the literature between PRCA and other determinants of adoption.[4]

INFRASTRUCTURE AND INFORMATION

Property rights are intrinsically linked to the distribution of technological inputs and information. At the community level, extension services have often favored those who control the greatest quantity of resources, that is, the wealthy. At the intrahousehold level, the norm in most patrilineal societies is for male heads of household to either own or have primary rights over land and other natural resources, even when they are not the primary users of the resource. Although this does not necessarily imply that they can easily exercise the right to deprive other family or community members of use rights over the resources they control, it does tip the balance of technology and information access in their favor. One sees a recurring pattern where extension services have largely targeted male heads of household, mainly because they were seen as the ones who controlled the land (Agarwal 1994; Fortmann and Rocheleau 1985; Lastarria-Cornheil 1997).

Property rights extend not only to the resources to which technologies are applied, but also to the technologies themselves. Adoption is highly dependent on access to technologies and information, and on control (that is, property rights) over a technology in order to implement it. Furthermore, property rights over technology will determine its marketability and the terms of

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[4] Conducting research on all of these factors is conceptually complex, and requires drawing on different disciplines. Ensminger (1992) notes that much of the new institutional economics examines the impact of property rights and other institutions, but treats the institutions themselves as exogenously determined. Anthropologists have done more research on processes of change in institutions themselves. Ensminger advocates not making all factors endogenous at the same time, but rather to shift back and forth, looking at different aspects of these relationships to get the full picture.

exchange for either the physical inputs or the technical information. Intellectual property rights to technology is rapidly becoming a prominent issue in the policy arenas of many developing countries today and has fundamental implications for access to technologies and information at both macro and micro levels. In particular, as the private sector assumes a growing share of agricultural research, the rights of farmers to access certain technologies may become increasingly restricted.

Collective action, in its capacity to build social capital[5] and foster empowerment, may act to strengthen the bargaining power of disadvantaged community interest groups (Agarwal 1994; Kurien 1995). This occurs through a process of building common objectives which identify the group and of magnifying the voice of individuals via the collective. If it succeeds in altering the distribution of local power and voice, collective action has the potential for realigning the distribution of technologies and resources to enable access to technologies and information (Sarin and Khanna 1993; Agarwal 1994; Chen 1983; Meinzen-Dick et al. 1997).

Likewise, formation of networks among community members can facilitate access to information by reducing the cost of acquiring it. Networks and other forms of collective action may also enable coordination of technology adoption efforts, whether they be individual or collective. For example, a communally managed seed bank may be established to facilitate individual tree planting, but also provide a forum for information sharing about the technology or other matters. Swallow et al. (1997b) show how the spread of information through *kabeles* (cooperatives) and interaction among neighbors facilitate the study of adoption of tsetse control measures in Ethiopia. The development of agricultural cooperatives in many countries is based on the premise that collective action for marketing of inputs and outputs can substantially reduce

[5] Putnam (1993) defines social capital as "features of social organization, such as networks, norms, and trust, that facilitate coordination and cooperation for mutual benefit."

costs, and make it feasible for farmers to use hybrid seeds, agrochemicals, or produce new crops. Although collective action may serve to diminish both technology acquisition and management costs, it will not necessarily make adoption profitable.

ENVIRONMENTAL AND PRICE RISK

Farmers' ability to manage risk efficiently can be affected by prevailing property rights and collective action institutions. For example, plot scattering, which takes advantage of micro-climate variations and reduces the possibilities that a farmer's full range of crops will be lost to pest or weather problems, must either be institutionalized through land inheritance systems, or requires active land markets so that farmers can optimally diversify their holdings through land swaps, purchases or leases. Land markets, in turn, depend on the presence of secure property rights. Plot scattering also requires that government does not prohibit fragmentation as often occurs based on the belief that land consolidation is necessarily more efficient.

Access to common property resources (CPRs) frequently functions as a buffer against risk. During drought periods, for example, agricultural households often resort more to CPRs to meet their subsistence needs, particularly for fuelwood and food (Jodha 1992). Pastoral and agro-pastoral populations occupying arid and semi-arid regions rely on herd mobility on communal rangelands to mitigate their risk exposure, engaging in opportunistic grazing (Behnke 1994; Galaty 1994; Swallow 1994). Collective action among herders not only establishes the membership, rules and enforcement of common property, it also enables risk sharing and diversification and inspires mechanisms for collective self-help (Mearns 1996; Thompson and Wilson 1994; Waller and Sobania 1994).

The bundle of property rights held by an individual bears significantly on their capacity to manage risk. In many parts of West Africa, women and 'stranger' farmers originating from outside the community are restricted from planting and owning trees since doing so would confer to them greater land rights (Berry 1988; Fortmann 1988; Rocheleau and Edmunds 1997). Inevitably, this limits their adoption of agroforestry and reforestation practices as well as other tree technologies which could diminish their exposure to risk (Neef and Heidhues 1994; Rocheleau 1988).

The literature on the links between property rights and risk management has tended to focus on the production side. Here collective action can also play a role, for example, in the sharing of germ plasm or pooling of labor. But collective action can also play a critical role in smoothing consumption in the face of uncertain and variable production. Support networks and reciprocity norms are frequently present in low-wealth rural communities to cope with these hazards, particularly given insufficient or complete lack of insurance markets. Sharing of output or other resources, and even participation in collective action can be seen as an investment in social capital, which can prove invaluable for the survival of the poor in the face of risk.

The spatial characteristics of risk are important for understanding the adoption or non-adoption of different technologies and for designing improved technologies which match the preferences of low-wealth individuals to mitigate risk. Idiosyncratic risks affect the individual or household. Illness, fires or job loss are some examples. Covariate risks, by contrast, are associated with environmental disasters or economic downturns which take their toll on large groups, communities or even the entire country.

Different forms of collective action and social capital may be needed depending on whether risks are idiosyncratic or covariate. In the latter case, collective action networks may need to involve a larger number of participants and be more heterogeneous so that the impact of the risk on individuals is differentiated. However, large groups and heterogeneity may introduce coordination problems and conflict, diminishing the potential success of collective action (Mearns 1996; Quiggan 1993; Olson 1971; Nugent 1993; Lawry 1990; Hansmann 1988 and 1990; Baland and Platteau 1996; Tang 1992). In contrast, collective action designed to confront idiosyncratic risk can be coordinated with an informal set of reciprocity rules or norms in a small community setting or even among a few neighbors, hence it is more likely to be an effective strategy.

WEALTH

In agrarian societies, wealth is intricately linked to property rights over natural resources, and this has a strong effect on people's options with regard to technology. In Pakistan, for example, farmers owning more land are wealthier, and are more likely to install tubewells; the control over groundwater which tubewells provide further increases their wealth (Meinzen-Dick 1996).

The bundle of one's property rights and the security of those rights combined with one's level of assets, income, and food security affect the degree to which one discounts possible future gains. Those who possess a higher quantity and quality of endowments will place a higher future value on the medium- and long-run benefits produced by investment in technologies. This is because they are less constrained by food insecurity and risks which undermine the ability to meet basic needs as compared to low-wealth actors. Social structures and power distributions furthermore bias technologies and the flow of technical information in favor of the wealthy, shaping adoption outcomes accordingly (Grabowski 1990).

By serving as a risk sharing device, collective action can alleviate food insecurities and other survival risks borne disproportionately by the poor to lower the degree of future discounting and therefore constraints on technology adoption. However, because collective action implies the exclusion of non-participants, negative equity outcomes emerging from collective action strategies are possible. Even among participants in collective action, equity is not guaranteed. Women, for instance, may be accorded less voice in the decision-making process while still being accountable for labor contributions, or being otherwise affected by the new management practices (Ahluwalia 1997; Athukorala and Zwarteveen 1994; Mayoux 1993; Sarin 1995). Nevertheless, collective action frequently becomes a means of realigning the distribution of gains from a resource by facilitating the adoption of more advanced technologies that require "lumpy" investments. For example, in Pakistan and Bangladesh, groups of small scale farmers or even landless people or women obtain rights to groundwater through collective purchases and management of wells and pumps, which provide for the water needs of members or other farmers in the community (Meinzen-Dick 1996; Wood and Palmer Jones 1990; van Koppen and Mahmud 1995). By applying collective action to enhance resource access, wealth acts as less of a constraint to obtaining rights to water resources and adopting water technologies.

CREDIT

One of the primary arguments made in favor of privatization of land tenure is that farmers need title to their land so that they can offer it as collateral for credit. For farmers who tend to have little or no collateral, it is hypothesized that privatization will permit them access to financial markets and increase the supply of credit available to them (Feder and Noronha 1987). As a result, agricultural investment and technology adoption is expected to follow.

However, formal financial institutions remain a rarity in many rural settings, particularly for the purposes of agricultural lending (Roth, Cochrane and Kisamba-Mugerwa 1993; Place and Hazell 1993). In fact, it is questionable how important a constraint formal collateral actually is relative to the overwhelming transaction costs involved in rural lending. Once means are found to reduce the transaction costs of lending, other forms of collateral may prove more appropriate, or even more effective, for reducing the risks of lending to low-wealth borrowers. The many examples of informal financial institutions undertaking successful group lending schemes which employ joint liability mechanisms attests to this (Adams and Fitchett 1992; Berger and Buvinic 1989; Bhole and Bhavani 1995; Chen 1989; Zeller 1996). These programs may be seen as substituting collective action (group formation and backing) for conventional property rights as a form of collateral. Implementing more progressive models of financial service provision may therefore accelerate the adoption of NRM technologies.

Some of the most noted forms of collective action in the literature center on the dynamics of credit and savings groups, which act to lower transaction costs of financial services and establish mutual accountability for repayment. Such groups provide a forum for building assets and self-reliance via savings programs as well as opportunities via credit for purchasing technologies and inputs to develop and maintain technologies. Group credit may also make larger scale, expensive technologies more feasible to acquire and operate if the costs of acquisition are shared by members and subsequently the use and maintenance of the technology (Agarwal 1994). Documenting the decollectivization of Mongolian pastoralism, Mearns (1996) notes that herders engage in jointly purchasing lumpy technologies which tend to be beyond the capacity of individual households to acquire. By investing and acting collectively, the costs associated with a particular technology are also spread out amongst the group members, lowering individual risk exposure and thereby potentially facilitating adoption.

Finally, credit groups may play a role in strengthening social capital formation and producing network externalities[6] so as to enhance opportunities for collective action in natural resource management and technology adoption. If groups are already formed around a common purpose and share a common set of norms and values, this reduces the information and coordination costs of their organizing around another purpose having already established a history of coordination and trust (Baland and Platteau 1996; Wade 1988; Nugent 1993; Mearns 1996; North 1990). In his analysis of irrigation in India, Coward (1986) illustrates how local investment and the creation of joint property rights to irrigation facilities forms the social basis of collective action for the ongoing management of irrigation works by community members.

LABOR

Within the households of most rural societies, property rights fail to correspond closely to labor responsibilities. A oft-cited statistic on the status of African women states that they perform around two-thirds of all the hours spent on agricultural-related work and own only 1 percent of the property (FAO 1985).[7] Carney and Watts (1991) demonstrate how the benefits arising from the employment of a technology were presumed to be below the opportunity costs facing those individuals exerting their labor, resulting in the withdrawal of women's labor.

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[6] In this case, 'network externalities' implies that the more people which have access to credit or participate in credit groups, the greater the probability of each individual having access. Therefore, the utility an individual receives in terms of access to credit is enhanced the more other people also have access.

[7] Given the pervasiveness of community-based land tenure in Africa, one assumes that the term, 'own' refers to holding primary use rights to land.

However, in some cultures women may need to contribute labor to their husbands' plots in order to get access to plots for their own production (Berry 1988; van Koppen forthcoming; Carney 1992; Meinzen-Dick et al. 1997). The introduction of new technology (for example, irrigation) can shift these labor demands and responsibilities. Von Braun and Webb (1989) attribute declines in women's labor productivity in a Gambian setting to their lesser access to labor-saving and yield enhancing technologies and shifting labor responsibilities away from agricultural production. Berry (1988) and Quisumbing et al. (1998) explore how the spread of cocoa as a commercial crop in Western Ghana led to men demanding a greater share of women's labor to farm cocoa crops owned by men. In some cases this has led to men giving women a stronger claim over land in compensation for the added labor burden (also see Okali 1983). This can be expected to have positive results for technology adoption by women.

Even when transaction costs are incorporated into the economic equation, institutions and political powers may foster sub-optimal outcomes, such as the inefficient distribution of labor, as a means of preserving the interests of the dominant group, be it gender, ethnic, class-based or a combination of these (von Braun and Webb 1989; Grabowski 1990; Folbre 1997). In the Gambia, for example, elite men used a tree planting program as a means of reclaiming land that had been given to women, who had been using the land for high-value horticultural produce (Schroeder 1993). In another example, irrigation project officials and local elite men in Burkina Faso acted to take land and water rights away from women who had been cultivating rice, and reallocate them as "family" plots, controlled by men. The result was a decline in productivity, as well as increased work burdens for women. In later schemes, local men insisted that women be included in decision-making on plot allocation, with better outcomes (van Koppen forthcoming).

Collective action can be employed as a means to exert control over individuals' own labor. In her study of a contract farming irrigation scheme in the Gambia intended to target women, Carney (1988) describes how women's property rights to land for rice cultivation were undermined by men. In several communities, women jointly responded by withdrawing their labor from rice cultivation, thereby undermining the successful adoption of contract farming technology. Collective action and reciprocity arrangements may also be employed as a means to overcome labor shortages faced by individual households, particularly in cash-scarce economies, thereby facilitating the use of more labor-intensive technologies (Kirk 1988; White and Runge 1995).

OTHER CONDITIONING FACTORS

Besides property rights institutions, other statutory laws and formal and informal community rules, norms, or ideas can act to expand or constrain people's choices with regard to technology. Erenstein and Cadena (1997) partially attribute the adoption of conservation tillage practices to state agricultural policies, including a law prohibiting the burning of crop residues. In South Asia, taboos forbid women to use ploughs, restricting agricultural productivity and reinforcing women's dependence on men (Agarwal 1994). Nevertheless, property rights institutions are pervasive in their scope; they frequently shape and reinforce other rules, both legal and normative. Property rights vested in the state provide the means by which laws are enacted which forbid the cutting of trees, which can then discourage cultivation of crops (Freudenberger 1994).

Although on the surface cultural norms which hinder technology adoption may appear to have equity, efficiency or environmental drawbacks, it is important to understand their more profound implications and not to write them off as being irrational. In many African rural societies, the capacity to perpetuate a cohesive community and lessen exposure to risk is rooted in kinship and marital practices, which have implications for the distribution of property rights (see Eyzaguirre 1988). In patrilineal societies, when men and women marry, women often move to their husbands' community and acquire secondary use rights to land without retaining rights to land in their birthright community. Likewise, the practice of having multiple wives means that male household heads periodically must redistribute land to accommodate newcomers as well as children. Altering the principles and property regimes which facilitate a cohesive community and the practice of polygamy may constitute increased exposure to environmental risk and diminished social security for women, at least in the short term. From an institutional economics perspective, the discounted transaction costs of change exceed the discounted benefits of the technology.

SUMMARY

Understanding the use of different technologies beyond the realm of crop technologies to include technologies appropriate for natural resource management requires a deeper appreciation of the spatial and temporal externalities embodied in various technologies, as well as the role played by property rights and collective action in facilitating or impeding adoption. As yet, little empirical research has been carried out documenting factors influencing technology choices applied to common property resources and how traditionally identified constraints interact with various property rights regimes to either weaken or assist in expanding the use of resource-enhancing technologies. Similarly, collective action, by internalizing the externalities produced by spatially dispersed resources and by lowering transaction costs of institutional change, may be instrumental in facilitating technological change in the NRM context.

Despite their important implications, it is important not to view property rights and collective action as a panacea for identifying constraints or enabling factors for adoption of NRM technologies. Rather, other constraining factors that are not influenced by PRCA abound. For instance, lack of market infrastructure and human capital constraints may hinder the use of mechanized wells for improved livestock management, given the inability to acquire spare parts and lack of indigenous knowledge to repair the wells. Property rights may constitute a separate issue constraining adoption in this context, being relatively independent of other constraints.

Because so many things tend to be related to property rights, it is easy to confound the effects of property rights with the effects of other related variables. For example, Adesina, Nkamleu, and Mbila (1997) found that, after controlling for other factors such as fuel and fodder scarcity, secure land rights were not a significant factor in adoption of alley farming in Cameroon (though secure tree tenure was). Similarly, Gavian and Ehui (forthcoming) found that in Ethiopia, land with less secure tenure had lower total factor productivity, but this was not due to farmers applying less inputs; rather, it was low quality of inputs or low skill in applying them that limited productivity. By modifying the existing property rights structure or facilitating collective action responses, more fundamental barriers can be overlooked while more problems may be created than solved. Instead of focusing on property rights or collective action in isolation, the purpose in introducing the PRCA framework to evaluate technology choices is to stimulate greater appreciation for how these issues manifest themselves in people's decisions about which technologies to employ, and the process of technology change itself.

4. TECHNOLOGY AND PRCA: A TWO-WAY MAPPING

Thus far, we have focused our discussion mainly on factors which have an impact on technology choices. However, technological change is a fundamental element of institutional change and, as shown in Figure 3, has feedback effects on the structure of property rights, collective action and other socioeconomic constructs. For example, Unruh (1998) shows that past adoption of cashew agroforestry in Mozambique has now become a major source of evidence used to secure land claims, and Kimberly Swallow's (1997) study of new cattle feeding technologies in Kenya changed the rules of access to a variety of feed sources, affecting both property rights and collective action. Otsuka et al. (1998) demonstrate how changes in physical and economic conditions such as the introduction of cocoa production, population growth, and scarcity of natural forests in Ghana has led to changes in the types of property rights found within communities; the property rights found within the community in turn set the options available to the household; and household allocation decisions affect the rights available to individuals. In effect, the framework displayed in Figure 3 is dynamic, driven by endogenous forces that operate at different levels.

The new institutional economics provides especially relevant analysis of the impact of technology on institutions. North (1992) argues that societies can only take advantage of technologies if they are able to restructure the institutions shaping their choice sets to provide incentives for increasing productivity and technology adoption. With increased specialization and impersonalization of markets, the number and scope of transactions grows as monitoring and enforcement of contracts becomes more difficult. In response to a widening in the overall costs of transacting, technologies and institutions need to adapt in order to reduce the cost of individual transactions.

North (1995) asserts that most decisions are made within the existing institutional framework, but the need to alter contracts puts pressure on rules and norms causing them to be modified. Incentives for modification, in turn, arise out of individuals' perceptions that they will benefit from restructuring exchanges. Such perceptions may stem from exogenous factors or, more importantly, a process of learning. The rate of learning determines the speed of economic change while the kind of learning guides its direction. North argues that the latter is rooted in the mental constructs of individuals and the incentive structures embodied in the institutional framework.

Putting this framework into a collective action context, we can assume that groups which share common environments and experiences are more likely to form similar mental constructs, which will shape their learning processes and perceptions. Presumably, this will foster a similar set of modifications which would be reinforced by communication within the group. Through a process of consensus-building and collective mapping out of strategies for altering contracts and norms, interest groups may consolidate their power so as to be better positioned than individuals to drive a process of institutional change. Whether collective action is initiated and ultimately succeeds depends crucially on the transaction costs it imposes over time.

In the case of collective action for the purpose of managing common property resources, costs are associated with design of the use rules, coordination of efforts, enforcement of rules and prevention of free-riding behavior, and the private and social costs resulting from exclusion of non-members. However, when weighed against the private and social costs of privatizing natural resources which embody widespread externalities, collective management exercised within common property regimes may have substantial efficiency and equity advantages over systems of individual management of private property. Under these circumstances, technologies which are designed for coordinated implementation by multiple users in a common property setting will prove to be most appropriate and the best candidates for adoption.

The choice of NRM technologies will inevitably shape the institutions underlying property rights and collective action. Technologies embodying substantial spatial externalities such as irrigation are likely to induce demand for common property regimes and collective action given the gains to be realized from coordinated efforts. However, if incentives for adoption are not built into PRCA institutions, information asymmetries are profound, and transaction costs of coordination and enforcement are not reduced, then technology adoption will not succeed and unsustainable outcomes may prevail. Using North's language (1992), the 'adaptive efficiency' of a society or community is the critical variable in ascertaining the potential for technical and institutional change.

Technologies with temporal externalities whereby the benefits of the technology are reaped at some future point in time carry implications for enhancing tenure security. Ploughing and planting barley establishes a claim on communal rangelands under the informal tenure system prevailing in large parts of North Africa and West Asia (Ngaido 1997a). However, such cultivation practices on fragile rangelands often lead to soil erosion, implying that existing property rights institutions can foster perverse outcomes in the face of competition and scarcity.

Planting trees may also establish or strengthen a claim on land. While this may be seen as a positive effect in terms of halting environmental degradation, promoting tree planting without understanding the interaction with tenure can lead to problems. The example in Section 3 of a tree planting program in the Gambia undermining women's productivity and power illustrates this (Schroeder 1993). The result was negative both in terms of efficiency and gender equality. Furthermore, if technologies are to be employed by women and other less enfranchised groups, the institutions which govern their rights to use a technology and capture the returns on their investment must be in place. In societies where women cannot plant trees because it is seen to strengthen their claim to land, agroforestry technology will only alter cultural norms if its benefits to women and to the community as a whole outweigh the costs faced by women seeking changes and the costs perceived by society of modifying the status quo.

Even though expectations of increased tenure security may encourage tree planting, incentives for tree management may not be present as suggested by Otsuka et al. (1998) in their study of land and tree tenure institutions in Western Ghana. Here farmers sought increased tenure security through extensive tree planting, thereby strengthening individual land rights. However, improvements in cocoa yields, a sign of better tree management, were not observed outcomes of having established stronger claims to land.

More generally, technologies that increase the value of a resource may induce privatization, enclosure, and the exclusion of some customary uses. Yet, the gains to some households and individuals from such institutional change are frequently offset by losses to others. Empirical studies have revealed a negative correlation between household income and reliance on CPRs for subsistence purposes (Jodha 1986 and 1992; Hopkins, Scherr, and Gruhn 1994). Women especially depend on resources from common property and “interstitial spaces” of private property (for example, hedgerows, reed beds) to provide for their family’s needs (Maggs and Hoddinott 1997; Agarwal 1994; Rocheleau 1988; Rocheleau and Edmunds 1997), or for their own tenure security where private property does not guarantee them access in the case of widowhood or divorce (Fortmann, Antinori, and Nabane 1997). Well-defined and secure property rights to CPRs are therefore highly important for the poor, and women who are poor in particular. Effective poverty alleviation strategies need to support common property regimes which enhance production of CPRs over the long-term and ensure fair distribution to more marginalized interest groups.

5. IMPLICATIONS FOR EFFICIENCY, EQUITY AND ENVIRONMENTAL SUSTAINABILITY

Adoption of new technologies is not an end in itself, either for agricultural researchers, policy-makers, or people who employ them in farming or managing natural resources. Rather, the outcome of technological change should be evaluated in terms of the contribution to broader goals of sustainable development. Growth, poverty alleviation, and environmental sustainability form a "critical triangle" for development (Vosti and Reardon 1997). Although there may be trade-offs between these three objectives, all are necessary and interlinked.

The way these play out in practice is strongly influenced by the nature of property rights and degree of collective action. Tenure security may elicit higher productivity and more efficient outcomes by ensuring only those who invest reap the benefits from doing so and that the right to do so is guaranteed for a long enough period in the eyes of the producer (Bruce 1993). Likewise, arguments stemming from as far back as colonial Africa maintain that tenure security provides the necessary incentive for producers to conserve resources by assuring them the future benefits (Lloyd 1977). However, the degree of tenure security within a community or among communities is not necessarily uniform. Wealth, power, and status are factors in determining one's tenure security and thus shape equity and environmental outcomes. Collective action becomes a critical component of tenure security in common property regimes, and a means of coordinating resource management across private holdings.

PROPERTY RIGHTS AND TECHNOLOGY ADOPTION

The effect on increasing productivity is a basic aspect considered in efficiency-oriented technology development. However, simplistic analyses of efficiency can lead to distortions. Many customary tenure regimes permit different users to exploit different "niches." Examples include pastoralists and cultivators on the same land; irrigation, fishing, and domestic use of water; or timber, firewood, and minor forest products (Swallow et al. 1997a). Technologies that increase the production of one of those components at the expense of other outputs do not necessarily improve efficiency. For example, introducing new tree species or forest management practices may maximize production of logs, but sacrifice kindling and minor forest products critical to the livelihoods of local residents (Meinzen-Dick et al. 1997).

Privatization of common property and land under communal tenure tends to lead to loss of multiple user rights in favor of more concentrated resource holding by a less diverse set of interests (Jodha 1992; Swallow et al. 1997a; Rocheleau and Edmunds 1997). The logic underpinning the privatization of tenure in Kenya during the 1950s rested on the belief that more entrepreneurial and supposedly more efficient farmers would acquire land from less efficient farmers (Swynnerton 1954). Subsequent research has linked conversion to freehold tenure to rising loss of access to land and other resources and large-scale land acquisitions by wealthy producers, government officials and speculators, with dubious gains for efficiency (Jodha 1992; Shipton 1988; Hitchcock 1980). Where the purchases are by large scale producers and speculators who are interested in short-term profits and have little stake in the long-term productivity of the land, soil fertility and other natural resources may be depleted (Jodha 1988 and 1992; Chambers et al. 1989; Arnold and Stewart 1989; Gupta 1987).

Examination of efficiency outcomes of new technology also need to include considerations of risk and transaction costs. Targeting wealthy households often shows the most rapid adoption and apparent productivity gains because farmers with large holdings will have a greater capacity to adopt mechanized and other capital intensive technologies which lend themselves to enhanced efficiency outcomes, particularly in labor-scarce environments. Households with low wealth face greater constraints and will likely place a higher value on stability of earnings and therefore be more risk averse than a more affluent household. The incorporation of transaction costs and risk considerations in efficiency calculations shows the rationality of the livelihood strategies employed by the poor, and the factors that need to be considered in understanding technology choices. This appreciation broadens the scope of technologies deemed to be efficiency improving so that they are less biased toward 'wealthy' concepts of efficiency.

Concerns over the equity outcomes of introducing new technologies have received considerable attention in the wake of the Green Revolution. Unless land holdings are distributed relatively evenly, improving the productivity of wealthier farmers by making technology available which are unsuitable for small scale farmers or those with less secure tenure exacerbates inequalities. Determining the temporal and spatial scale of technologies as in Figure 1, and relating this to the local distribution of tenure provides an indicator of where this is likely to be problematic. For example, the scale neutrality and short-term benefits of HYVs meant that small farm size and tenancy were not constraining (though risk aversion and credit constraints often limited adoption by small farmers, at least initially -- see Hazell and Ramasamy 1991). By contrast, tubewells or tractors are "lumpy" investments that require a longer time horizon and larger service area to be profitable, and hence are more likely to be purchased by larger farmers or groups of small farmers with long-term rights to resources (Meinzen-Dick 1996; Binswanger 1978). The fact that scale-neutral technologies (for example, new varieties) often require investments in large-scale technologies (for example, irrigation) to be effective can also undermine adoption of seemingly equity-enhancing innovations.

Although common property regimes do not guarantee equitable outcomes among their members, they do accommodate multiple users beyond the household level and are therefore better equipped than private property to spread benefits more evenly. However, recent research has cautioned against assuming common property regimes and collective action embody impartial sharing rules and equal distribution of power (Agrawal and Gibson 1997). In his research on communally owned land in Portugal, Brouwer (1992) maintains that mechanisms of social redistribution and security shape equity outcomes of resource exploitation, rather than property rights themselves. Although users have equal rights to the resource, ability to exploit the resources is conditioned by one's access to private means of production.

Equity considerations do not only apply between households, but also to gender differences in access to and control over technology and resources. Although it cannot be said that male dominance in many societies stems from their monopoly on property rights, ownership of property enhances the status and bargaining power of individuals within both the household and community (Agarwal 1994, 1997; Meinzen-Dick et al. 1997; Folbre 1997). Greater control over resources tends to enhance men's influence over community power structures and wield political leverage with government officials and others responsible for technology distribution as well as infrastructure and market development. The same is true for the wealthier strata of society (Kurien 1995; Grabowski 1990). Technologies and their supporting infrastructure will therefore mainly reflect the interests of men who control the most substantial resources unless a sufficient degree of collective action emerges capable of reshaping political outcomes so that government and other suppliers of technology and infrastructure intervene with policies to override these biases.

COLLECTIVE ACTION AND TECHNOLOGY ADOPTION

As discussed in Section 4, various technologies will be more efficiently employed with collective adoption after material and transaction costs are assessed, whereas others will be more amenable to individual adoption. Alternatively, collective action may influence technological choices based on their anticipated impact on efficiency, equity and environmental sustainability.

Used as an advocacy or political tool, collective action can be used by marginalized interests groups to challenge property rights institutions, existing political and cultural institutions, and technology adoption. Agarwal (1994) reports how women's groups in Bihar, India succeeded in getting land titles assigned to women in their own right as part of a broader peasant land reform struggle. In another example, organization by artisinal fishermen in Kerala, India led to restoration of their coastal common property rights, state financial assistance and eventually a season ban on trawling by commercial fishermen (Kurien 1995).

Collective action can be used to prevent the use of certain technologies, as seen in Katon, Pomeroy, and Salamanca's (1997) study of a fishers' organization in the Philippines preventing the use of beach seine nets, dynamite, and strong poisons for fishing. In other cases it can serve to modify the features of a particular technology or its mode of adoption. In both the Philippines case and the case of the artisinal fishermen in India (Kurien 1995), local groups constructed artificial reefs as a means to lure more fish and increase their food supply. Harvesting technologies thus shifted from extractive practices to artificial reefs which not only benefitted small scale fishermen, but also enhance the productivity of coastal resources. Greater integrated community participation in decision-making about the design, implementation and adaptation of technologies may not only ensure that new technology does not disproportionately and inefficiently increase the workload of marginalized groups, but actually functions to reduce overall labor inputs.

LINKAGES AND TRADEOFFS BETWEEN THE COMPONENTS OF THE CRITICAL TRIANGLE

Inequities may also carry environmental implications. For instance, use of pesticide technology by large farmers may generate negative externalities for small farmers if they do not have access to it, especially if the chemicals eliminate predators who would otherwise keep the pest in check. Inadequate access to land and technology by the poor can lead to over-exploitation and degradation of resources. Conversely, where indigenous property systems have broken down so that members no longer have an assurance that they will benefit from investments or long-term management practices, individualization of resources can contribute to adoption of more sustainable resource management practices (Bruce 1993).

Objectives of efficiency, equity and environmental sustainability frequently involve tradeoffs, particularly in the short run. Efficiency maximization involves selection, whether it is managers, labor, capital or land. Some inputs will lose relative to others, and this leads to inequitable outcomes. Even within input categories, substitutions are made. In the U.S., efficiency-enhancing technology improvements combined with certain macroeconomic factors have increased the demand of skilled labor at the expense of unskilled labor (Krugman and Lawrence 1993).

Efficiency and environmental goals are often at odds as well. Efficiency measures tend to assess only the private financial costs of inputs and neglect social and environmental costs. Privatization of such resources as rangelands and fisheries has been advocated as a measure to control stocking rates and improve resource productivity so as to enhance profitability (Cheung 1970; Picardi 1974; Johnson 1972; Foss 1960; Demsetz 1967). However, one sees in Africa where failure to account for environmental variability and fragility has resulted in overgrazing, soil erosion, and other forms of environmental degradation on many privatized ranches and areas appropriated by sedentarization schemes (Keya 1991; Hogg 1987; Gilles and Jamtgaard 1981). Likewise, poverty alleviation strategies may initially rely on extensification techniques which lead to resource degradation.

However, the tradeoffs are perhaps overstated. In the case of natural resource management techniques such as agroforestry, environmental degradation can raise the perceived value of products and conservation of the resource base to where it becomes worthwhile to invest in new technologies (Scherr 1995). Also, when efficiency criteria are placed in a dynamic framework, the value of a resource over time is captured and conservation often emerges as the optimal strategy. When transaction costs and risk considerations are incorporated into efficiency calculations, the livelihood strategies employed by the poor can be understood as economically rational. Likewise, when productivity measures include the value of non-traded goods and services which poor households (and especially women within those households) obtain for their livelihood and security, an equitable distribution of resources, or technologies that favor the disadvantaged, may be seen as highly productive. Appreciation of less tangible economic and social dynamics broadens the scope of technologies deemed to be efficiency improving so that they are less biased toward concepts of efficiency which consider only physical inputs. Thus, recognition and attention to the complexity of measuring efficiency is necessary to prevent the poor from being left behind or hurt by technologies and to narrowing equity gaps.

Tradeoffs may also become less relevant in the long-term. Compatibility between efficiency, equity, and environmental outcomes can arise over time with the development of more land intensive and conservation-oriented technologies that either evolve or are designed to be both accessible and affordable to poor farmers and herders (Vosti and Reardon 1997).

6. POLICY IMPLICATIONS AND AREAS FOR RESEARCH

Despite the growing body of theoretical and empirical studies of how property rights and collective action institutions can constrain or facilitate the adoption of agricultural and natural resource management technologies, the effects of these institutions has often been understated because most of these studies have looked only at the direct effects (or has been overstated because they have been confounded with the effect of other factors.) This paper has proposed a conceptual framework for analyzing the factors affecting technology choice which not only includes the direct effects, but also indirect effects as they are filtered through changes in property rights and collective action institutions (Figure 3). In doing so, it seeks to provide a new approach for framing empirical research which specifies and tests these indirect effects.

Whereas the literature has taken account of the effect of property rights on the technology adoption process, empirical research on the importance of collective action on application of NRM technologies remains largely underresearched. Likewise, empirical research is lacking on assessing the impact of technology on an array of adoption constraints and opportunities, including PRCA. New institutional economics has produced much theory, but notably little in the way of actually measuring technology's role in the evolution of institutions. Shifting to the tail end of the conceptual framework, there is a need for both theoretical and empirical research to enrich our understanding of the interaction between technological choice and efficiency, equity and environmental sustainability. This component is especially critical for illuminating improved strategies aimed at poverty alleviation, the overarching goal of much national and international research on technologies for natural resource management.

Testing these relationships empirically is a serious methodological challenge, given the number of factors involved. Moreover, because institutional change is path dependent, the answers from one site will not necessarily apply more broadly. However, detailed analyses of the interrelationships between technological and institutional change are nevertheless needed to understand the dynamic processes if technologies are to be adopted, and to improve the productivity, equity, and sustainability of resource management.

Institutions do not always need to adapt to technology. Even the existing base of knowledge of property rights and collective action provides guidance for developing technologies that fit the institutional, as well as the physical environment. Assessing the degree of tenure security and collective action in a location can be used as a starting point for developing techniques with an appropriate scale and time horizon, as indicated in Figure 1.

On the policy side, strengthening local institutions of property rights and collective action increases the probability that people will use many of the new technologies for resource management. However, no single instrument provides the key to understanding and influencing people's use of different technologies. This paper has illustrated some of the complexities in the linkages between property rights, collective action, and technology choices. Because of the many interrelationships, and the number of site-specific factors involved, it is not straightforward to prescribe a certain type of property regime as "most appropriate" for a particular technology or resource management practice. But even if it were, identifying policy tools to develop such property rights is far from straightforward. Simply passing laws specifying the rights and responsibilities of individuals, groups, or government agencies is not enough. Laws alone do not create property rights unless there are institutions to monitor and enforce those rights. If we recognize the importance of legal pluralism, we see that local law derived from a number of sources may have equal or greater influence on actual behavior. Thus, the evolution of property rights must be understood as a process of institutional change, in which resource users themselves play an active role. While this certainly limits the ability of outside "experts" or policy-makers to shape property rights, it also recognizes that local users themselves have greater knowledge of their specific physical, socioeconomic, and institutional context.

Similarly, collective action cannot be externally dictated (unless there is considerable coercion). However, there are policies that have been shown to be effective in fostering local organizations for voluntary resource management activities. Employing a cadre of institutional organizers is one approach that has been effective, especially in the irrigation sector (Korten and Siy 1988; Manor, Patamatamkul, and Olin 1990). In Namibia, an organizing partnership of communities, NGOs and the Ministry of Tourism and the Environment enables the integration of GIS and participatory mapping for establishing institutions to jointly manage wildlife resources (Tagg, Holme, and Kooiman 1996). These organizers, who may work for an NGO, university, or government agency, spend time in the communities, discussing what needs to be done, developing consensus, and encouraging local participation in both direct activities and in decision-making about the structure of collective action. While this approach can be time-consuming and somewhat expensive in terms of organizers' salaries and field expenses, it is often a relatively small portion of total development project costs, and has shown high returns in terms of uptake and sustainability of resource management practices (Bagadion and Korten 1991; Meinzen-Dick, Reidinger, and Manzardo 1995). The use of organizers can be thought of as subsidizing initial leadership development and as an investment in the institutional infrastructure required for sustainable resource management.

Finally, property rights over natural resources can provide an important policy tool for strengthening collective action in their management. Just as individuals are unlikely to invest in soil fertility, terracing, or tree planting unless they have secure tenure, communities cannot be expected to invest in managing long-term practices if they have no long-term rights to the resource. Yet many governments have been unwilling to transfer rights to water, irrigation infrastructure, rangelands, or forests when they devolve management responsibility to user groups. The issues of community rights and ways of creating new common property resources (in place of government ownership) are emerging as critical issues in devolution programs (Svendsen 1997).

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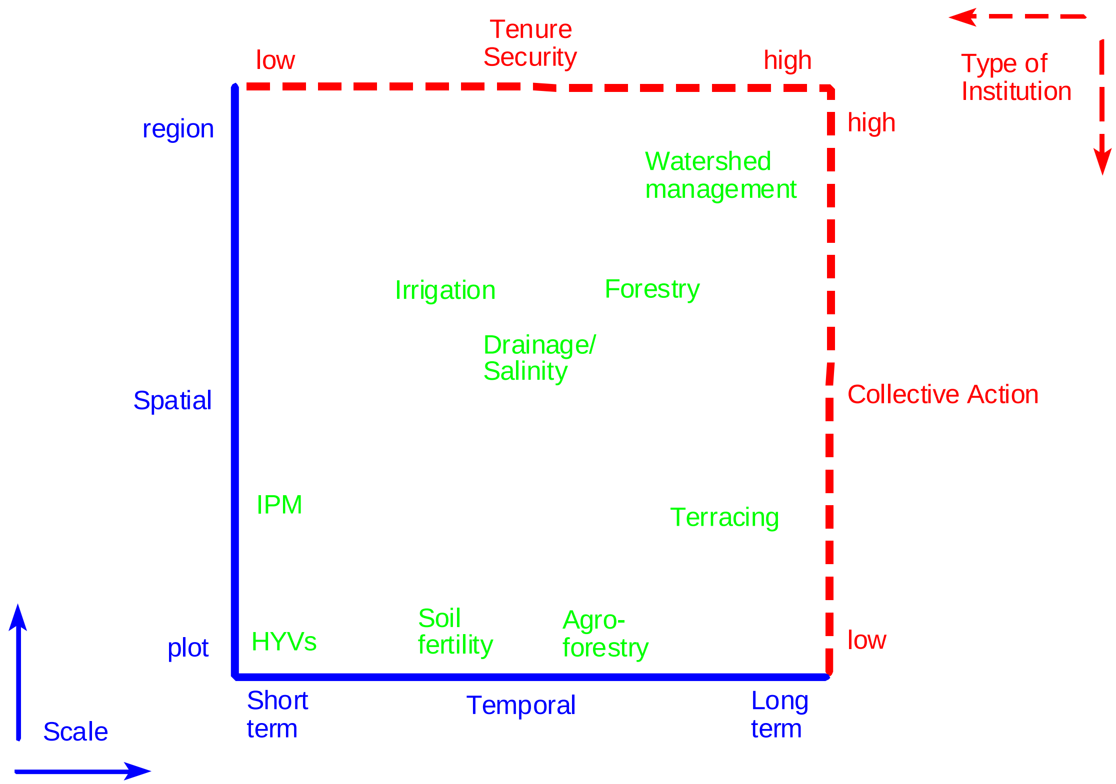
List of SP-PRCA Working Papers

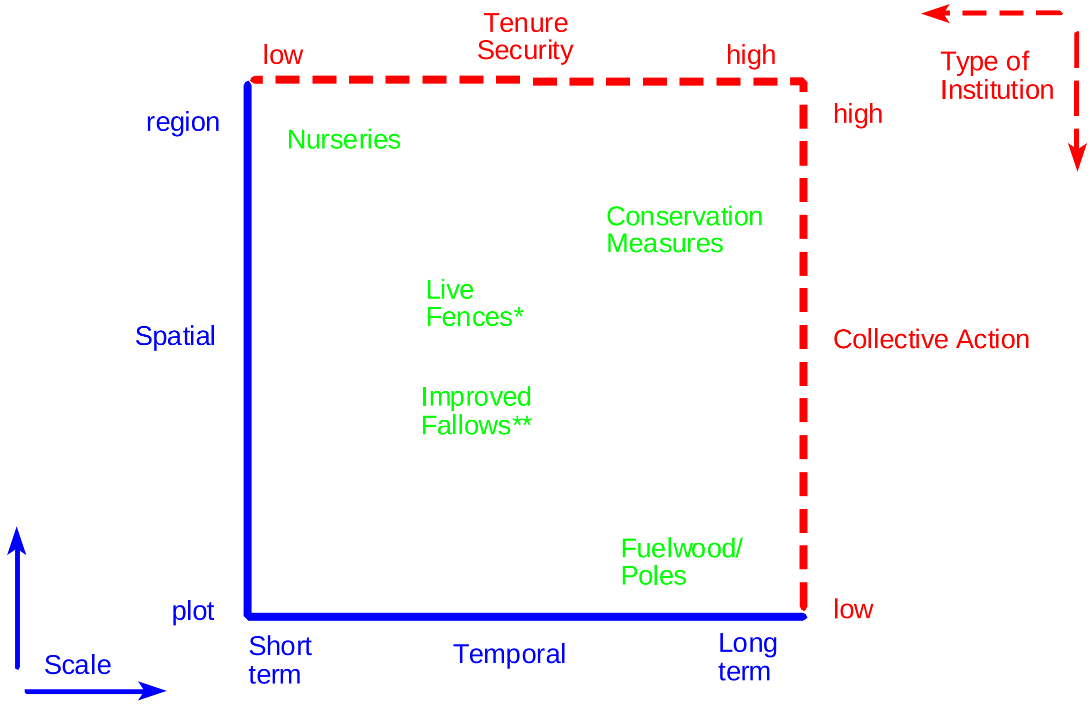
01*Property Rights, Collective Action and Technologies for Natural Resource Management: A Conceptual Framework*, by Anna Knox McCulloch, Ruth Meinzen-Dick, and Peter Hazell, October 1998.

Figure 1 Property rights, collective action, and sustainable agriculture/NRM practices



Note: Location of specific technologies is approximate, for illustrative purposes.

Figure 1A Property rights, collective action, and agroforestry technologies



Note: Location of specific technologies is approximate, for illustrative purposes.

* Requires changes in herding practices if fallow crop species is palatable to livestock.
** May require changes in herding practices if fallow crop species is palatable to livestock.

Figure 2 Conceptual framework: Direct effects on technology adoption

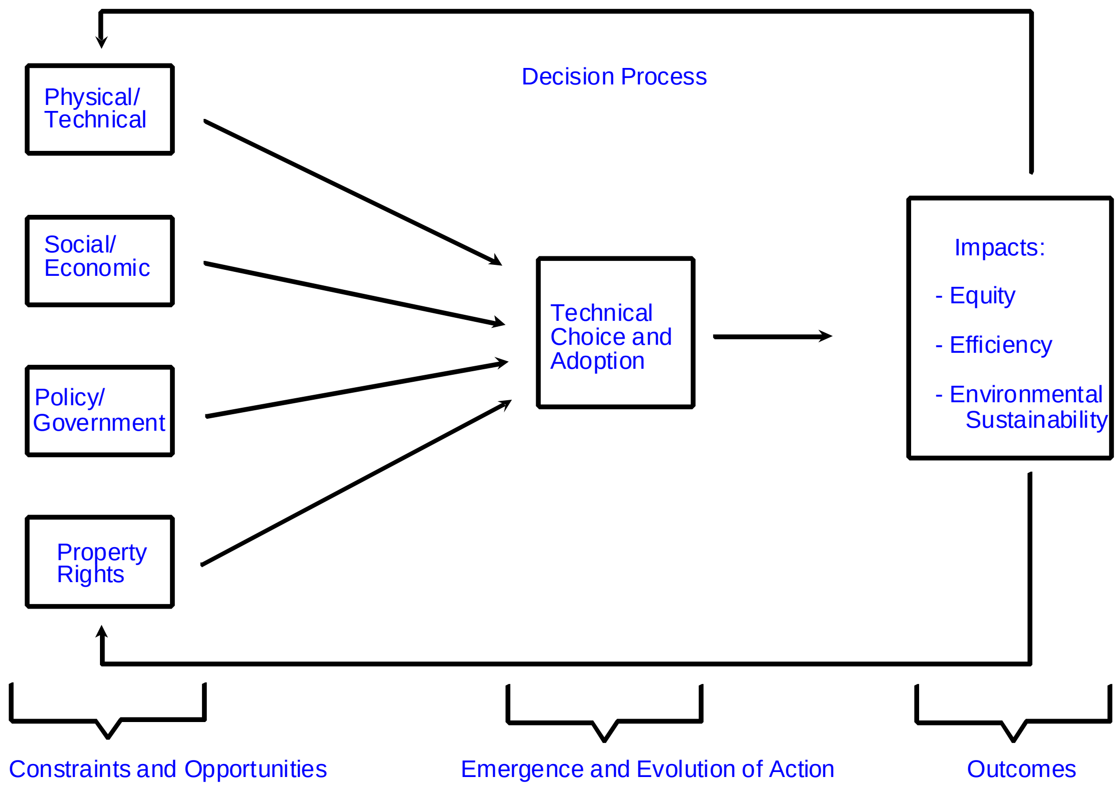


Figure 3 Conceptual framework: Indirect effects on technology adoption via property rights and collective action