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ASSESSING THE RELATIONSHIPS BETWEEN PROPERTY RIGHTS AND TECHNOLOGY ADOPTION IN SMALLHOLDER AGRICULTURE: A REVIEW OF ISSUES AND EMPIRICAL METHODS

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ABSTRACT

Studies of the relationships between property rights and technology adoption are complicated in several respects. First, there are challenges involved in defining and measuring property rights and tenure security. Second, there are several different valid purposes for undertaking such studies and each purpose may require a different approach. Third, there are a number of difficult theoretical and empirical issues involved in such studies, particularly in defining technology, identifying key dimensions of property rights, and accounting for the endogeneous determination of property rights.

Through a synthesis and evaluation of previous studies, this paper identifies key issues and develops guidelines for conducting research on the relationships between property rights and technology adoption in smallholder agriculture. It seeks to benefit researchers and policy makers wishing to undertake or interpret empirical research. The topics addressed in the paper are: definition of scope and terms; key issues pertaining to the relationships between technology adoption and property rights variables; data collection and measurement issues; and analyses and interpretation of findings. The primary target groups for this paper are researchers and policy analysts.

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ASSESSING THE RELATIONSHIPS BETWEEN PROPERTY RIGHTS AND TECHNOLOGY ADOPTION IN SMALLHOLDER AGRICULTURE: A REVIEW OF ISSUES AND EMPIRICAL METHODS

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1. OBJECTIVES AND RATIONALE

The overall objective of this paper is to provide researchers and policy analysts with a better understanding of the key issues and guidelines for conducting research on the relationships between property rights and technology adoption in smallholder agriculture. The primary target group for this paper is composed of researchers who have advanced training in micro-economic theory and statistics, but are not specialists in property rights per se. An important secondary target group are policy analysts who review empirical studies and draw lessons for policy design.

The study of property rights and technology is complicated in several respects. First, there are challenges involved in defining and measuring property rights and tenure security. There now is general agreement that tenure security is related to a number of rights over land and other resources that may or may not be vested in individuals. But there is no general agreement about how rights should be measured, aggregated, or otherwise manipulated to derive quantifiable measures of tenure security.

Second, researchers can have several different reasons for undertaking a study of the relationship between property rights and technology adoption. Each reason may have different implications for methodology. Perhaps the most common reasons are:

1) providing input into discussions of property rights policy;
2) defining recommendation domains for existing technologies or those under development;

3) identifying traits that will make new technology attractive to farmers;

4) assessing the impacts of technology on objectives such as production and poverty alleviation; and

5) identifying groups (e.g. women) that may not be able to adopt a technology because of the property rights institutions.

Objective (1) suggests the need for a good dialog between researchers and policy makers (local or national) to ensure that the study will have a positive impact on the policy formulation process. The other objectives imply closer collaboration with applied researchers, development institutions, and farmers themselves.

Approaches to definition of property rights variables and modeling the causes and consequences of property rights also differ across the five objectives. For objective (1), the results must have policy relevance. That is, the analysis must involve variables that policy makers understand and can influence through the policy instruments under their control. A clear structural model in which the effects of the policy variable(s) can be distinguished from other variables is required. This structural model also needs to show the linkages between property rights and the other important outcome variables. Policy makers are likely to be interested in the effects of property rights on technology adoption, productivity, sustainability, equity and income. To fully address objectives (4) and (5) the researcher also needs a structural model that isolates the impacts of individual variables. On the other hand, a cost-effective predictive model is needed to achieve objectives (2) and (3). The research, extension and development agencies that use the research outputs will be most interested in identifying and measuring the variables that can guide them in targeting new technologies. In that case, they may be most interested in proxy variables that are easy to measure.

The third challenge is that there are a number of difficult theoretical and empirical issues involved in such analyses. Some of the major issues are:

6) defining the technology, including the spatial and temporal dimensions of the costs, benefits, and scale of adoption;
7) identifying the dimensions of property rights that have the greatest effects on technology adoption;
8) selecting the appropriate level or levels of observation and analysis—plot, individual, farm, community;
9) reducing potential biases in sampling;
10) accounting for the endogenous determination of property rights;
11) controlling for the confounding effects of property rights with other explanatory variables correlated with property rights; and
12) making appropriate interpretations of the empirical results.

As a result of these complicating factors, there have been several different approaches to empirical testing of the links between property rights and technology adoption. Through a synthesis and evaluation of previous studies, this paper seeks to benefit those who wish to undertake or interpret empirical research in the future. This paper does not develop a particular structural model of the relationship between property rights and technology adoption. Instead, it draws upon models that have been recently developed by analysts such as Feder and Feeny (1993) and Sjaastad and Bromley (1997).

The remainder of the paper is as follows. Section 2 briefly delineates the boundaries within which this review is organized. Section 3 reviews key issues pertaining to modelling and conceptualizing technology adoption and property rights variables and the relationships between them. Section 4 discusses specific data collection and measurement issues arising from Section 3. Section 5 addresses some key aspects associated with analyses and interpretation of findings. Finally, Section 6 is a re-emphasis of the major issues and points raised in the paper.

2. SCOPE AND DEFINITIONS

To enable this review to be tractable and thus useful, we have deliberately put some boundaries around different dimensions of the review.

TECHNOLOGIES

This paper will focus on the intensity of adoption and management of technologies by individuals for use on agricultural land. Agricultural land includes home gardens, fields, fallow lands and grazing lands. Collective adoption of technologies is not considered here.

PROPERTY RIGHTS

Property rights considered here are the rights of individuals to benefit streams produced from agricultural land (including all natural resources on the land). We review literature relating to both customary and formal (e.g. statutory legal) tenure systems that affect smallholder farmers. This includes the situations of legal pluralism in which customary and statutory legal systems overlap.

TOPICAL SCOPE

The review concentrates on methods for empirical analysis rather than theoretical modelling. Attention is given, however, to the links between theory and empirical analysis.

GEOGRAPHIC SCOPE

The methods reviewed should be relevant to smallholder agriculture in developing countries, especially where there is insecure social and legal support for customary and formal rights.

3. MODELLING AND HYPOTHESES

It is noted above that the type of structural model that is developed to guide an empirical study depends upon the purpose of the study. Some of the questions that need to be considered when developing a structural model are:

- What characteristics of a technology suggest a relationship with property rights?
- What aspects of technology adoption and use are most important to model and test?
- What dimensions of property rights are important in the adoption decision?
- How are property rights expected to affect technology adoption?
- How is technology adoption hypothesized to affect property rights?
- Are property rights variables correlated with other variables that affect adoption?

- What are the most important social-spatial scales for the problem at hand?
- What characteristics of a technology indicate a relationship with property rights?

The nature of the technology or investment will affect the hypothesized relationships between technology adoption and property rights. Technologies whose cost and benefit streams are of very short duration will be less affected by property rights than those whose benefit streams are lengthier. Thus, a land manager who faces a high probability of losing her rights to land may still use fertilizer on her crops. Other types of investments, though of a longer-term nature, may be undertaken if the costs of investment are very low. This may be the case with the direct sowing of a small number of trees. For many other types of investment, such as terracing, fencing, water harvesting, windbreaks, and medium term fallowing, property rights are expected to have greater effects on incentives. The extent of those effects will depend on the degree of insecurity. However, the effect of insecure tenure is not necessarily pervasive. High expected profits can overcome the negative incentives that result from insecure property rights.

The type of technology also affects whether or not it may have an impact on property rights. Tree planting is widely cited as an investment that confers strong land rights to individuals (Fortmann and Bruce 1988; Suyanto et al. 1999; Snyder 1996; Baland et al. 1999). Fallowing, on the other hand, is a type of land investment that may weaken land rights. This may be because land that is left uncultivated can be perceived as excess to household needs and thus become subject to claims by other extended family members (Place and Otsuka 1998). Investments in water wells and pumps may confer a high degree of exclusivity over the water resource. Investments in fruit trees, however, may be subject to a myriad of secondary use rights by community members. Many other types of investments may have little effect on property rights, particularly those with short duration.

WHAT ASPECTS OF ADOPTION ARE IMPORTANT TO MODEL AND TEST?

A few remarks about what constitutes “technology” and “adoption” are appropriate at this point. Technology is often used broadly to encompass both physical/biological structures or objects as well as management practices. Most often, researchers are interested in the adoption of specific technology components (e.g. fertilizer) or integrated technological packages (e.g. high yielding crop variety with fertilizer). However, it may be more important to study the traits or functions of these technologies. For example, rather than analyzing the adoption of all types of improved maize varieties or a particular variety, a study could be designed to examine the adoption of all short duration maize varieties. Similarly, one might wish to study the adoption of trees, not by species, but by grouping together all species that farmers use to enhance soil fertility. Grouping criteria will depend on one’s hypothesis about what function of a particular technology constitutes the underlying rationale for adoption.

Generally, it is difficult to identify exactly when a technology has been adopted. Researchers instead often record current use of the technology. This may be unsatisfactory for new technology where farmers may be merely experimenting or in areas where projects have had strong influence and possibly have provided incentives for farmers to use particular technologies. Informal discussions and qualitative research can identify whether these issues are important in the study area. If so, additional questions could be added to formal surveys to distinguish among different types of users of technology (see Section 4).

Technology adoption is often measured by a single binary variable: the technology is present or absent on a farm at a particular time. A binary variable may be adequate for assessing farmer investment in, for example, traditional water wells. There are five special characteristics of traditional water wells that lend themselves to this present/absent measurement. First, traditional wells are very familiar to farmers and thus farmers are relatively certain about the associated payoffs and risks. This implies that farmers are willing to make full rather than partial investments. Second, farmers are usually not given any external incentive to make an investment in a traditional well so that one can assume it is demand driven. Third, traditional wells are indivisible. A farmer cannot choose to invest in half a well. Fourth, traditional wells do not normally require complementary inputs in order to be functional and thus are independent of constraints associated with other technologies. Lastly, once they have been built, wells exist for a long time, compared to technologies like crop varieties that come and go.

However, researchers are usually interested in technologies that differ from traditional water wells in one or more of those four characteristics. First, researchers are often interested in technologies that are under development or have been recently made available to farmers. In those cases, it may be important to explore the farmers' knowledge and information about the technology. Does the farmer have accurate information about the technology? Are there systematic biases in the information systems that limit access to information by certain types of farmers (e.g. women, migrants, minority ethnic groups)? Decision-tree modelling may be appropriate for separating the effects of information from the effects of property rights (Gladwin et al. 1997).

Second, new technologies are often made available to farmers in less developed countries through some type of adaptive research, extension or development project. In that case, it is important to consider the amount of discretion that the farmer exercises over the investment. Erroneous and misleading results can result from studies that confuse adoption with acquiescence to the wishes of researchers or extension workers. There are also farmers who test or use a technology solely because they may desire to copy other villagers or to obtain intangible benefits such as prestige from visits by researchers. If possible, it is preferable to restrict studies of adoption behavior to farmers who do not have direct contact with such projects. If not, then researchers should endeavor to account for this potential effect in the analysis.

Third, it is often necessary to quantify the intensity of technology adoption beyond simple presence or absence of the technology on farm. In this, there usually are tradeoffs between the benefits and costs of more refined measurement of the intensity of technology adoption. For example, the adoption of trees can be measured by the number of trees per farm, the density of trees per hectare, the number of particular species or types of trees per hectare, or the standing biomass of trees per hectare, among others. Where investments are divisible and relatively easy to make (like trees), a binary assessment of adoption may fail to detect important variation in technology adoption. In this case, some type of further narrowing of the technology (say to certain species of trees) or quantification would be essential.

Fourth, farmers often adopt components of technology packages in a stepwise manner, with some components necessarily pre-dating others. In that case the absence of a technology at a particular time may be unrelated to farmer plans to adopt the technology at a future time. Equally, the absence of a technology at a particular time does not mean that the farmer has never used the technology. Again, decision tree modeling may be appropriate for understanding farmers' strategies vis-à-vis the technology. Based on this, the collection of historical data is valuable and may be warranted in some cases such as when there are clear relationships between technologies, or links between farming systems and technologies, or links between household life cycle and technology traits. If indeed the duration were more relevant than current presence of a technology, this would suggest the use of survival or hazard models that deal explicitly with temporal issues. In addition, complementary relationships between technologies would suggest the use of models that account for these relationships (e.g. multi-nomial logits).

WHAT DIMENSIONS OF PROPERTY RIGHTS AFFECT ADOPTION?

The literature suggests that the three important dimensions of property rights are exclusivity, security and transferability. The exclusivity dimension refers to the way that relationships among potential right holders are defined. Under open access, no one has rights or duties. Under common property, rights are defined to coexist for an identified group, with other groups or individuals having duties to respect those rights. Under communal property, rights of ownership are vested in groups, but rights of usufruct and limited rights of transfer may reside with individual households. Under private property, individuals or households may enjoy rights to the exclusion of others. However, private property does not necessarily imply a high degree of exclusion. In Africa, it is common for people to have secondary rights to the livestock feed, firewood and water produced on private land.

Place et al. (1994) describe key components of tenure security to be freedom from interference from outside sources, continuous use, and ability to reap the benefits of labor and capital invested in the resource. Embedded in this description are three dimensions of land rights: breadth, duration, and assurance. Breadth refers to the types of rights held. Generally the more rights held the more secure those rights. Households with rights to alienate land or to make long-term improvements on land would be considered to be more secure than those with only use rights to land. However, there often are certain rights, such as the right to bequeath, that are critical to motivate long-term investment. Some rights may be indicative of larger bundles of rights. For example, someone who holds the right to sell may automatically hold the right to rent out. Duration refers to the length of time over which the individual/group may enjoy specific rights. Assurance refers to the ability of individuals to exercise their rights. Despite adequate breadth and duration of rights, assurance may be lacking where overlapping rights exist or where there is weak enforcement of rights.

Transferability refers to the ability of the right holder to transfer rights over the resource to others. Primary examples of this include the ability to select heirs and bequeath land, the ability to rent or lease land or trees to others temporarily, and the ability to dispose (alienate) an asset. Transferability is valuable by increasing the ability to raise cash through sale or rental of the property (also through credit) and by allowing farmers to endow heirs with key assets.

HOW ARE PROPERTY RIGHTS HYPOTHESIZED TO AFFECT TECHNOLOGY ADOPTION?

It is generally accepted that, at least in sub-Saharan Africa, there are both direct and feedback relationships between property rights and technology adoption. First, the property rights that govern the use of a particular plot of land will affect farmers' adoption and use of technology on that land. Second, the adoption and use of technology has feedback effects on property rights. Some of these feedbacks occur within a prevailing property rights institution. Others put pressure on the property rights institution to change. This sub-section is concerned with the direct effects of property rights on technology adoption. The following sub-section is concerned with the feedback effects.

Exclusivity

Property rights that are generally regarded as being 'private' may confer rights to individuals, nuclear families or lineages. Private property rights may also be encumbered by secondary rights or public restrictions. It is generally hypothesized that the degree of exclusivity has a positive effect on the incentive to produce, invest and adopt technology. The greater the exclusivity, the greater is the incentive to adopt technologies that are fixed to the land. Thus, for example, institutionalized seasonal grazing of farm land (lack of exclusivity) may discourage certain types of investment such as the planting of perennial crops. However, free grazing livestock may well encourage investment in fencing and adoption of non-palatable plants and trees. Also, Baland and Platteau (1996) suggest that there may be circumstances in which less exclusive land rights may help people to pool the risks associated with new innovations or technologies.

Security

Feder and Feeny (1993) distinguish different possible effects of insecure property rights on technology adoption. First, rights of short duration provide a direct disincentive for farmers' to undertake investments in land. Relatedly, when the breadth or assurance of rights are inadequate, local rules may not protect an individual's claim to benefits from investments. This has often been noted in the case of women, who lack rights to undertake long-term investments (Kerkhof and May 1988, McLain 1992; Place 1995; Mugo 1999; for trees). Whether breadth or assurance is hypothesized to be linked to technology adoption depends upon the specific technology/property rights context such as the payback period of the technology. Second, insecure property rights will increase the relative price of long-term assets to land and thus reduce the capital intensity of farming.

Transferability

The transferability of land rights, including rental, bequest, temporary and permanent gift, and sale, may affect technology adoption in three ways. First, restrictions on transferability may reduce the incentives of current residents to adopt technologies likely to generate benefits beyond their likely tenure. For example, if an elderly man cannot pass a piece of land to his heirs, then he is likely to exploit existing trees rather than plant new trees. In this case there is a clear interaction between property rights and life cycle of the household. Second, restrictions on transferability are likely to reduce the market exchange of land and thus may affect the efficiency of land allocation. Households with most incentive to undertake investments on certain land types will thus have limited access to that land. As a consequence, it might be expected that land that is purchased might receive more investment than others. At a community level, one would expect a greater level of technology adoption in communities where rights to sell land were more prevalent. Third, restrictions on transferability will reduce the possible use of land as collateral. In theory, land is the most important collateral asset in rural areas. However, it is only valuable to potential lenders to the extent that it can be sold by lenders to third parties, in case of default. In many parts of Sub-Saharan Africa, it is difficult to sell land, particularly to people from outside the community. As noted above, the importance of specific transfer rights in a given area depends on whether such rights are exercised.

HOW IS TECHNOLOGY ADOPTION HYPOTHESIZED TO AFFECT PROPERTY RIGHTS?

There are two possible types of feedback effects between technology adoption and property rights. First, an existing property rights institution may provide a farmer with different types of property rights to a particular plot of land (in terms of exclusivity, security and transferability) depending upon their investment in that plot. For example, qualitative studies have documented the ability of certain investments, such as in land clearing and tree planting, to enhance tenure security (e.g. Snyder 1996; Quisumbing et al. 1999). The expectation of more secure property rights may thus stimulate farmers to undertake certain investments (see for Uganda, Place and Otsuka 1999 and Baland et al. 1999; for Burkina Faso see Braselle et al. 1998). More research is needed to assess the temporal duration of this effect and to assess the aspects of tenure security that can be expected to change following such investments.

Second, the adoption of certain types of technology may result in pressure on property rights institutions to change. For example, recognition of investment in trees has induced changes in tenure rules in Uganda and Zambia. In Eastern Zambia the adoption of improved fallows by a few thousand farmers prompted the Paramount Chief to pass a new bylaw to that prohibits free grazing of livestock (personal communication with Chief, October 1998). In Kabale, Uganda, secondary grazing rights continue, but there are now strict fines for damage to young trees planted by households. The introduction of certain technologies can also modify rights of women over resources. For instance, women who were not allowed to plant timber and pole trees by their husbands were allowed to plant trees for soil fertility in Uganda, as these were considered to be different types of trees (personal communication, Two Wings Agroforestry Group 1996).

If property rights variables are likely to be treated as dependent variables, then one must try to identify variables that would influence changes or differences in observed values and plan for the collection of those data. Furthermore, if property rights and technology variables influence each other, then it is important to construct an appropriate structural model to account for these relationships. This can be complicated by multiple scale considerations. For example, property rights institutions may prevail at the level of a community or ethnic group whereas technology adoption may be an individual decision. This may call for the integration of community and household level studies. Whether at multiple or single scales, multiple-equation systems should be specified. In a simultaneous system, one must identify, measure, and include variables that can help to identify the equations. Often, this comes down to identifying an explanatory variable that explains only one of the dependent variables. These will be re-examined in Section 4.

ARE PROPERTY RIGHTS VARIABLES CORRELATED WITH OTHER VARIABLES THAT AFFECT ADOPTION?

There are strong theoretical reasons to believe that some property rights variables are correlated with other variables that may be directly related to technology adoption. At an individual level, women and men may differ systematically with respect to the ways they can acquire rights to land and the subsequent rights they enjoy to this land. For instance, women may tend to rely more on temporary land acquisitions and therefore have less secure rights to land than men. In this case, a tenure variable related to acquisition or land rights may capture other gender-differentiated impacts. Other variables that may be related to property rights variables at the plot or household level might be wealth (e.g. wealthier household may have stronger rights to land), soil fertility (purchased parcels may be of better quality), and distance from house to parcel (closer parcels may be more secure). At the community level, there may be systematic relationships between property rights and population pressure and distance to market. Theory suggests that individualization of land rights strengthens under greater population pressure and proximity to developing markets by virtue of heightened competition for land and higher returns brought on by better access to markets. The presence of such correlations suggests more complicated structural models with multiple equations. This means that strategies for sampling and data collection will have to be modified accordingly.

If multicollinearity is anticipated, then it is important to explore theoretically the relationships between property rights and other explanatory variables. Otherwise, misspecification of the model can lead to erroneous conclusions about the importance of individual variables. For example, it may be that the effect of gender on technology is transmitted entirely through indirect effects on farm size and tenure security. If this is the case, then the inclusion of gender, farm size, and tenure security in a single equation model would show gender to be insignificant. But if a structural model was well thought out, the effect of gender might emerge as significant in a reduced form regression. Adjusting the original model will likely imply the collection of additional variables that might be used to help identify equations of a more complex model. All these concerns are lessened, however, if the objective is only a predictive model. In this case, identifying inexpensive variables associated with adoption takes priority over teasing out the causal relationships among individual variables.

ARE THERE DIMENSIONS OF THE PROBLEM THAT ARE RESOLVED AT DIFFERENT SOCIAL-SPATIAL SCALES (PLOT, INDIVIDUAL, FARM, COMMUNITY)?

With respect to social and spatial scales, two dimensions are important. The first pertains to the right holder(s) and the second to the resource unit. Right holders could be individuals, households, pastoralists, user groups, communities, and the like. Resource units could be individual trees, wells, and various land units such as forests, pastures, agricultural parcels, or fields within parcels. There is no single unit(s) of observation that is best nor even appropriate to address all tenure issues. The best unit(s) of observation will vary according to the particular issue under study. Most of the empirical studies dealing with property rights and technology adoption use households or individual household members as key right holders and land parcels or fields as the main resource for which property rights are examined.

How can one best select the appropriate units? Perhaps it is best to indicate the types of cases where the standard practice of using the household right holder/land parcel resource combination may not be the most appropriate. One is the issue of how rights of women may affect technology adoption. Using the household as the key right holder unit will only be able to compare the cases of female-headed and male-headed households. Obtaining information for all male and female adults within a household is most effective to look at intra-household distinctions (see Golan 1994; Mugo 1999). Moreover, women's rights over land may not identical across the entire farm. Women may enjoy more secure rights over specific plots of land than others. These subtleties must be understood prior to the analysis of the more complex tenure issues. Other cases requiring special attention to unit of observation are: trees may have to be differentiated according to species or function; higher level tenure variables that are uniform for many households within a defined area; where there is significant fragmentation of landholdings; resources that are shared by households.

Though these cases suggest that there may be a superior strategy for selecting units of observation, it should be stressed that conducting analyses at multiple units of observation can yield different insights into the property rights-technology adoption relationships. In some cases, the use of a single observational unit may lead to erroneous conclusions. For example, a farm level analysis could mask many important relationships taking place on different land parcels or fields where rights may differ. On the other hand, focusing only on the smaller units can sometimes lose sight of the broader implications of tenure on household level decision-making. For instance, many studies have found negative relationships between rented parcels and investment in technology using household-parcel level analyses. However, this may obscure effects such as the effect renting land might have on enabling households to make longer term plans on their owned parcels. Therefore, one should always consider whether the units of observation selected would lead to unambiguous answers to the key questions being studied.

The most common right holder studied in property rights studies is that of the household. These studies begin with the assumption that most decisions concerning agricultural investment and technology adoption are made at the household level, normally by the head of household. Following from this, property rights over a specific resource are treated as uniform for the household, bearing the property rights of the household head. These approaches are well accepted in the literature and therefore are generally well founded to study certain issues. For example, focusing on the rights of the household head in a study of the effect of the right to sell land on technology adoption is quite sensible. Sales cannot be initiated by other members of the household or community. In such studies, the most common resource units are farms or plots. It is now well recognized that in many rural settings, households may acquire more than one plot of land using different methods of acquisition. Furthermore, rights of a particular household member over these plots could differ. Therefore, it is now routine to collect property rights information at plot level.

Studies at the individual (i.e. household member) level are intended primarily to look at the implications of gender on technology adoption. One of the key differences between males and females is in their control and access to resources and the benefits streams they produce. Thus, a key feature of these studies is to look at gender differences in methods of land acquisition, rights to land, and then to relate these to resource management in general, and technology adoption in particular. Studies that account for individual difference also often are cognizant of the possibility for finding different property rights arrangements across plots. For instance, wives may have more control over decisions in one plot than on the rest of the farm and property rights studies may focus on the question of whether this asymmetry leads to difference in technology adoption.

Studies at the community level are rare. This is due in large part to the observation that agricultural land is managed directly by smaller units and as such the smaller units are more pure observational units. But another reason may be related to measurement problems: how can one accurately measure technology adoption at the community level? What property rights variables are appropriate at the community level and which can be measured? But increasingly, the power of such studies is being recognized (Pender et al. 1998; Suyanto et al. 1999; Baland et al. 1999; Place and Otsuka, 2000;). Community level studies are ideal for examining property rights aspects that tend not to vary over smaller units or areas. Those that may be linked to ethnicity, such as grazing practices, land acquisition methods, and the rights of women, may be quite variable across communities, but vary little within communities. Community level studies enable researchers to study wider areas for less financial cost. The drawback is in the compromises that must be made in terms of precision of data. Moving to higher levels of aggregation brings even more difficulties in conceptualizing meaningful technology adoption and property rights variables. Often the aggregation of very diverse intra-national variation in these variables renders a national level analysis weak. However, some innovative work has taken place at the national level, at least in formulating property rights variables (e.g. Deacon 1994).

4. DATA COLLECTION AND MEASUREMENT

In collecting data, some iteration between individual and group interviews and between qualitative and quantitative research techniques is usually appropriate. Qualitative techniques are used to identify priority issues for study, determine the population to be considered in the study, identify variables for stratifying the population, identify local definitions of property rights, determine the sensitivity of the questions, and interpret quantitative results. Quantitative techniques (including quantification through participatory techniques) are used to validate qualitative results, statistically test hypotheses, estimate elasticities and prioritize policy and action steps.

POPULATION AND SAMPLING STRATEGY

Several issues need to be considered early in a study of this type. Once the specific technology(s) is defined, it is important first to define the population from which a sample may be targeted for further analysis. Then a sampling scheme must be devised. Lastly, one must decide whether the observations drawn should be georeferenced in order to be able to relate observations at different spatial locations and scales.

Population

Identifying the population on which to base a sample for a study of a property rights-technology adoption study can be challenging. It is less of a concern when the study is focused on adoption or impact of a specific technology in which case the researcher is confined to defining the population from within the feasible adoption domain (e.g. an area surrounding the points of technology dissemination). This will provide a sample of communities and households with different degrees of adoption that is necessary to examine the technology-property relationship from either direction. It is more of a difficulty for a researcher who wishes to identify representative property rights systems, as detailed information about property rights is not generally available across large areas. A further problem is that there can be peculiar property rights institutions based on ethnicity and this will affect the degree to which specific empirical results may be generalized. Nonetheless, there is a great deal of dispersed qualitative information about property rights systems and these can be exploited to assist in developing study populations. Rather than being overwhelmed with the nuances distinguishing different property rights systems, classification on specific characteristics or incentives may be more fruitful in delineating pathways for extrapolating results.

Sampling

Once the population is defined, the next step is to develop a sampling scheme. Among the first issues to address is that of unit of observation. Given that this is the focus of the above section on social-spatial scales, this discussion is postponed to the corresponding empirical section on measuring property rights at aggregate levels. Regardless of the unit of observation, when the purpose of the study is to examine factors affecting technology adoption or impact, it is essential to have a sufficient number of adopter and non-adopter outcomes in the sample. From a statistical perspective, ensuring a reasonable number of cases for each outcome improves the ability to find statistical and reliable links between factors and different outcomes by reducing standard errors and influence of outliers.

Whether the sampling procedure should be random or stratified depends on the size of intended sample and the distribution of technology. If a very large sample is planned (say over 1,000), then sufficient numbers of adopters and non-adopters might be found from a random sample, even if adoption rates are relatively low, say between 10–20 percent. More frequently, studies can only afford smaller samples in the range of 100–200 households. For technologies that are used by a large proportion of the population, a random sample of households/individuals may suffice. However, for new technologies with limited exposure, stratification of specific geographical areas, if not households themselves, may be necessary. The implication of non-random sampling is that there is over-sampling of areas where the technology has been introduced. The implications of this on interpretation and extrapolation are important and are discussed in Section 5.

Most studies of technology adoption have not stratified households on the basis of property rights variables. The first reason is that it is not always possible to obtain sufficient information on property rights with which to stratify. Second, if property rights variables are endogenous, such stratification can lead to econometric complications in terms of model misspecifications and omitted variable biases. Third, important categories of property rights will be automatically included if the sample is sufficiently large and not too narrow geographically. An indirect way to obtain a representation of different tenure arrangements would be to stratify on the basis of ethnic group and population pressure or any other variable that is available and is related to property rights variables (e.g. Place and Otsuka 1998; Baland et al. 1999). Where such techniques are inadequate and secondary data is not available, rapid censuses have been found to helpful to generate sampling frames based on tenure variables (e.g. Place and Otsuka 1998).

Georeferencing

Georeferencing is a technique to improve the ability to relate locations of study units to one another and to other phenomenon in the landscape, such as towns or roads. To the extent that aggregations of phenomenon and distances to key physical or manmade structures are important in creating incentives for behavior, analyses can be improved by using georeferencing. Georeferencing should definitely be used in community level studies, where primary data collection can be easily linked to other variables likely to differ across communities. Georeferencing may be less important for studies at lower levels (because information on other variables may be too coarse to vary at these levels), but an exception is the creation of variables of aggregation (pockets of like households, areas of similar land characteristics) or measures of dispersion (fragmentation of household plots). A cost-benefit analysis of georeferencing should be undertaken as part of the planning of the study.

MEASUREMENT OF TECHNOLOGY ADOPTION

First, we consider the identification of 'real' adoption. This is especially relevant to the CGIAR where there is pressure to demonstrate impact from their research. Farmers may undertake rather lengthy experimental processes before deciding whether to adopt a technology. An understanding of recent technology expansion is helpful in distinguishing testers from adopters. An adopter may be one who has expanded the level of use over a number of years. Spending some time to understand these differences is most critical for researchers unfamiliar with an area or technology.

The most common form of measuring technology adoption is through the use of a binary variable indicating its current presence or not on a particular plot. This leaves unanswered questions about how the technology found its way onto the field. Was it demand-driven or were farmers rewarded for trying it? This approach also crudely places observations into one of two categories and may result in grouping of households with quite dissimilar behavior. For instance, a household that has planted 1 tree may be treated as equal to the household that has planted 1,000 trees. A binary measure works better for larger more indivisible investments such as a well or the formation of a bench terrace. Whether simple binary measures or more quantitative assessments are made, it is important to verify that wilful investments were made. Variants on the use of binary measurements are to incorporate into criteria for adoption evidence of prior expansion or willingness to expand in the future (e.g. Manyong and Houndekon 1999).

If investment levels are well distributed, using a binary measure results in considerable loss of information. As a consequence, the statistical relationship between property rights and investment may differ fundamentally in the cases of binary and quantitative measure of investment. Likewise, it becomes more difficult to isolate the impact of property rights from other possible explanatory variables. Another concern emerges in regression analysis. First, because property rights variables are themselves often represented by discrete variables, there is a chance that regression models will not converge. This probability increases the more unbalanced are the frequencies of adoption and property rights.

When measuring technology adoption, it is often easy to scale up to higher levels. For instance, with a measure of plot level technology adoption, a similar variable can be created at a household level or a community level (given that suitable sampling methods were employed). Thus, a binary plot level variable on adoption of terraces can be aggregated to form a community variable on the percentage of plots or households with terraces.

Quantifying the level of adoption is used in some cases (see Lin 1991; Bellon and Taylor 1993; and Adesina and Zinnah 1993 for examples). Some examples of quantifying adoption would be the meters of similar types of conservation strips, meters of live fencing, and area under a particular tree crop. However, there are challenges to the quantification of adoption including the evaluation of the quality of the technological investment. A terrace bund formed by earth, vegetative strips, and stone is technically superior to that formed by earth alone. In this case, comparison of ‘meters under terrace’ would not provide an appropriate measure of intensity of adoption. Some investments are more easily quantified, e.g. the number of trees planted, but here too quantifying can become costly if there are many different tree species to condition upon and if within each, there were many different dates of planting. There are trade-offs between precision and cost. Certain cases suggest that further precision is more important. If property rights are expected to have very specific impacts, say on a particular type of tree rather than trees in general, then all trees cannot be grouped together. This is true in the case of timber trees in Uganda (Place 1995). On the other hand, one shouldn’t undertake an exercise of mining the data to find any type of relationship. Focusing on narrow definitions rather than the bigger picture can lead to erroneous conclusions.

If duration of an investment or the date of investment is important to measure, this is usually relatively easy to collect at the plot or household levels. For some types of technologies, e.g. the use of a particular crop variety or management practice, it may become more difficult. In conducting community level surveys, finding average dates of adoption is practically impossible. Instead, one might need to settle with first dates of technology adoption, which is achievable, though average duration among those who adopt is more easily understood. A survey could thus be modified not merely to tick whether a technology is present or not, but whether it had ever been present and when. This can provide the necessary information to investigate adoption rates between two points in time (e.g. Knudsen 1991; and Fischer et al. 1996) or sequential adoption of related technologies or components (e.g. Feder 1982).

There are two additional points here. The first is that a technology that is observed may well have been inherited (especially something such as tree crops) and an understanding of what was already present on the land at the time of inheritance is very important. For example, there may be quite perverse effects where only the current stock of trees is measured. A farmer with a relatively high current level may in fact have inherited a much larger number of trees and has only reduced his density. Meanwhile another farmer with a low current number of trees could have started with none and planted all those observed. Second, if technology adoption had in fact taken place several years prior to the survey, then it may be wise to attempt to match property rights and other explanatory variables as much as possible to the conditions at the time of adoption.

MEASUREMENT OF PROPERTY RIGHTS

The concepts of exclusivity, security, and transferability are often captured empirically through various measures of rights to resources. Exclusivity has been proxied for by responses to questions on the necessity of households or individuals to seek approval or to notify particular individuals, groups, or authorities outside of the household prior to exercising a right (see Migot-Adholla et al. 1991). Excludability may also be proxied by collecting information about the extent of secondary rights to resources. This is very pertinent for community level surveys to gain an understanding of the general level of excludability of rights. The particular context of the technology-property rights issue will suggest the specific types of rights or approval mechanisms that are more appropriate.

Security has been approached in several different ways. One common way is to capture the breadth or number of rights held by individuals (Migot-Adholla et al. 1991; Besley 1995; Hayes et al. 1997; Braselle et al. 1998). Others have identified hierarchies of land rights and then measured the presence or absence of key land rights (Migot-Adholla et al. 1991; Hayes et al. 1997; Baland et al. 1999). This approach is appropriate if, from the perspective of the respondents, some rights are more important than others or if possession of more powerful rights implies possession of many less powerful rights (Schlager and Ostrom 1992). Another common approach is to use the method of acquisition or local tenure categories as a proxy for tenure security (Matlon 1994; Gavian and Fafchamps 1996; Ayuk 1997; Adesina 1999; Manyong and Houndekon 1999). Normally, purchased land is hypothesized to be most secure, rented and leased land the least secure, with other types of acquisitions lying somewhere between. Some studies have endeavored to differentiate categories that contain a large proportion of cases. For instance, Lawry and Steinbarger (1991) and Adesina (1999) distinguished between divided and undivided inheritance acquisition methods. Likewise, Place and Otsuka (1998) distinguished four different inheritance patterns among the patrilineal and matrilineal ethnic groups in Malawi. A few studies have directly asked farmers about their perceptions of the risks of losing land (e.g. Kisamba-Mugerwa and Barrows 1989). Informal discussions in the study area assist greatly in the identification of important tenure security groupings.

Transferability is almost always measured either by the right to sell land, rent land, or by the presence of land title (Feder et al. 1988). Whether these are useful variables to distinguish different degrees of transferability can be evaluated by obtaining information about the prevalence of land market transactions. For example, if few land sales take place, it is not clear that the right to sell is linked strongly to transferability per se. Information about rights to sell and rent can be obtained rather easily, but care should be taken to understand the degree to which individuals can make free and independent decisions. Often, extended families or elders must approve sales. In some societies, land must first be offered to members of one's extended family before it can be placed on the open market. The presence of land title or any other formal document (e.g. purchase agreement) is also easy to enumerate. In the case of title, because updating land registers following land transfers is often an endogenous choice of farmers, titles to land are sometimes outdated, being in the name of the previous owner, often the father. The separation between titleholder and user may not mean much in terms of tenure security, but it may have an important implication for the ability of the user to transfer land.

There are a group of variables that are often described as components of land tenure, though they are not directly linked to security or rights. These are variables that describe land holdings patterns, such as plot size, farm size, distance between homesteads and plots, and fragmentation (or scattering) of plots. For the size variables, the data collection issue for this variable is really the accuracy of farmer estimates. In areas where land surveys have been done, their knowledge is normally quite accurate. In other areas, there may be significant errors in estimation. It is advisable to collect information on total farm size and to check this with information (or direct measurements) of individual plots or fields. Distance between the homestead and specific plots is fairly easy to collect, be it in by space (e.g. kilometers) or time (e.g. minutes of walking time). Growing population pressure has led to increasing fragmentation of farm holdings in some areas. Farmers might therefore operate one or more inherited plots, one or more purchased plots, and one or more rented plots at the same time. Farm fragmentation as a variable could be measured by the number of plots or by more sophisticated measures that take into account the size of plots or the distances between them (e.g. dispersion indices can be used—see Blarel et al. 1992).

While these proxies of tenure security are important in understanding the fundamental links between property rights and technology adoption (see Haugerud 1989; Blarel et al. 1992; Carter et al. 1994; and Place and Hazell 1993), they are often not variables over which formal policy makers have direct influence. There may be additional legal property rights instruments for which an analysis might be quite important. For instance, a very relevant research issue would be the impact of the issuance of formal titles to land on investment and agricultural productivity. The impact of title has been tested by several authors (Feder et al. 1988; Roth et al. 1994; Pinckney and Kimuyu 1994; Alston et al. 1996; and Place and Migot-Adholla 1998) and reviewed by Atwood (1990). Other legal instruments that have appeared in empirical research include contracts with the state and other farmers through tenancy (Gavian and Ehui 1999).

Three issues regarding the method of data collection are of particular relevance to property rights studies. First, some types of topics or questions are believed to be quite sensitive to respondents. This should be first investigated in more informal discussions by the researchers. However, considering the wide variety of information on property rights reported in the literature, such concerns do not appear to be widely validated. Second, concepts of tenure security and rights are not so straightforward to articulate in questionnaires. For instance there may be confusion over the distinction between what rights may be exercised versus what rights are commonly exercised. This is problematic both for enumerators and respondents and researchers should prepare for considerable training on these this topic. Third, not all types of respondents are equally informed of property rights issues. Often, it is the male head of household who is best able to respond about household level rights and details of acquisition methods. In fact, if the head is a male, the wife may not be willing to divulge detailed information about property rights. On the other hand, in studies of individual household members rights, it is recommended to seek responses from the particular individuals concerned rather than accepting responses from a single respondent. The same principles apply in community studies; it is important to identify respondents with appropriate knowledge of the subject while still capturing the varied viewpoints of different stakeholders.

TIMING OF STUDY RELATIVE TO TIME PERIODS OF ADOPTION AND REALIZATION OF PAYOFFS FROM ADOPTION

The different reasons for conducting a study of property rights and technology adoption can imply different timings for the study. Organizations that wish to identify recommendation domains or desirable traits of new technology can benefit greatly from studies conducted during early stages of technology dissemination. The feedback of information from these studies can prevent wasted resources. Studies that are more geared towards influencing policy are best served by allowing technology development and transfer processes to mature for a longer period. In studying the impact of technology, there are benefits from studies implemented at different times. Early studies can identify improvements to feedback into the research process, while late studies can give better assessments of overall impact. In all cases, it is important to be sure that farmers are beyond an early testing phase.

If the study is seeking to look at the influence of technology adoption on property rights change, then a longer time frame is clearly warranted since such institutions cannot be expected to change rapidly. Moreover, it may be that only after widespread technology adoption would there be sufficient pressure on institutions to change.

Measuring the feedback of technology adoption on property rights

If technology adoption is expected to affect property rights variables, a couple of important data collection issues arise. First, it is best to be able to document a change in property rights from one point in time to another. For a plot, this might be from the time of acquisition or the period just prior to the adoption of technology, to the current period. The variable(s) selected to represent property rights must be such that they are not static (so method of plot acquisition would not be appropriate) and can be relatively easily recalled by respondents. The second issue concerns the ability to distinguish the property rights-technology adoption link from the technology adoption-property rights link. To some extent this means understanding the temporal processes involved. But there may several distinct processes. Therefore, at a statistical level, it is important to identify variables that might affect one of the links but not the other so as to be able to identify the parameters associated with the different directional relationships.

Some examples of variables and their likely impact on the property rights-technology adoption complex are:

Those affecting adoption only:

- household size, size of family labour force, certain plot biophysical
- characteristics (plot size, slope)

Those affecting property rights only:

- ethnic group, leadership & community political variables

Those affecting both:

- farm size, marital status of household, age of head, gender of head

These are not fixed nor defensible in all cases. They must be developed for the particular situation under study.

DATA COLLECTION WHEN EXPLANATORY VARIABLES ARE EXPECTED TO BE CORRELATED

When correlations between property rights and other explanatory variables are probable, then adjustments to data collection may be in order. Examples include land titles and farm size (Carter et al. 1994) and gender and mode of land acquisition (de Zeeuw 1997 and Manyong and Houndekon 1999). One of the best ways to identify the influence of the property rights variable(s) from others is through sampling strategies. The goal is to have a sufficient variation in the sample so that there are adequate numbers of cases contrary to the systematic correlations (e.g. women with strong rights or low populated areas with strong rights). It is best to deal with this through stratification.

However, a priori, it can be exorbitantly costly to design a sampling frame to achieve this. One remedy is to increase the size of the sample in order to increase the number of different interactions among the independent variables. Increasing the sample size has long been known as one of the best ways to mitigate against multicollinearity problems. If multicollinearity is recognized only at the data analysis stage another option is to do some informal, quick, and inexpensive data collection to distinguish real driving factors from symptomatic variables (e.g. to solicit expert opinion from key informants from a village). If all these methods are unavailable, then the researcher can apply some of the econometric techniques available to deal with multicollinearity such as ridge regression (Goldberger 1990).

MEASURING PROPERTY RIGHTS AT MORE AGGREGATE LEVELS OF OBSERVATION

The section reviewing measurement of property rights at the plot and household levels showed that at the purest level of specific resource and specific right holder, very detailed assessment and precise measure of property rights can be made. At higher levels, such as a community, information will be collected from spokespersons on behalf of the community leading to some fundamental differences in the quality of information. This means that the information will be subject to less detail, for example averages are reported and the rich variation in property rights systems are lost. There may also be less accuracy in reporting. Thus, some property rights arrangements could be reported to be much more important than what actually occurs in practice. Collecting reliable information at community level can be challenging. It is of course good practice to interact with individuals or groups of different characteristics to be able to assess the variety of tenure arrangements. Older people will be the key resource people for obtaining historical information. In some cases, it may be necessary to build up community level property rights variables from rapid surveys of households in order to be assured of reliable data (Suyanto et al. 1999). Participatory tools may be used to help obtain more precise property rights variables. For instance, for variables that are highly related to spatial location (e.g. extent of commons, area under broad tenure regime such as customary versus estate), respondents might be able to draw boundaries on maps allowing for more accurate assessment of the importance of different tenure arrangements. If the boundaries are subsequently stored in a GIS database, the tenure variables can be linked to a host of other information similarly stored (Place and Otsuka 2000).

5. ANALYSIS AND INTERPRETATION

This section will explore alternative statistical/econometric techniques used as well as the interpretation of the results for research and policy.

There are at least three important components of the statistical analysis:

- investigation of statistical significance of a relationship
- investigation of the importance of a relationship and its interpretation
- extrapolation of results to impact policy

These are discussed in consecutive sub-sections below.

ANALYSIS

Multivariate regression techniques are almost always preferred over simpler univariate or bivariate analyses in the statistical investigation of the property rights-technology adoption link. A major reason for this is that property rights are often associated with other plot and household characteristics so that simple comparisons of adoption under different property rights will likely bias the strength of the relationship. Technology adoption is almost always in the form of a limited dependent variable. Where it is binary, a logit or probit regression model is appropriate. Where adoption values may take many positive values (e.g. level of adoption), a tobit model is normally appropriate. If adoption is measured by proportion of area under the technology, truncated models should be used instead. Maddala (1983) provides a highly readable introduction to these cases, while other authors (e.g. Greene 1993) may provide more accessible treatments of the underlying econometrics.

Two complications to this methodological approach are the observance of multiple technologies and the endogeneity of property rights. Many studies of technology adoption find several technologies of interest. In many cases, there are clear conceptual relationships between different technologies, e.g. terracing and tree crops, zero grazing and improved fodder, and water wells and fencing. When the number of individual lined technologies is small, or if some grouping of technologies can be made, a multinomial logit regression analysis can be used. If there is a large number of technology variables, most studies have resorted to an assumption of independence between them and have used single equation models. Simultaneous models involving limited dependent variables are not yet well developed and are not used in this literature. A study by Hayes et al. (1997) though, applied a two-stage procedure to tease out the indirect effects of land rights on productivity through their effects on investment.

When property rights both affect technology adoption and are affected by technology adoption, a simultaneous equation model is appropriate. If the property rights and technology adoption variables are continuous, then the three-stage least-squares estimation method can be used. This is rarely the case, however. For limited dependent variables, single equation methods for handling endogeneity (such as two-stage least-squares) have been utilized and techniques such as bootstrapping have been employed to correct for the resulting biases in estimated standard errors of coefficients (Braselle et al. 1998; Baland et al. 1999). The treatment of simultaneous equations consisting of limited dependent variables is neither well developed in this literature nor in other applications.

An additional complication in the development of simultaneous models is that property rights and technology adoption are not always measured at the same unit of observation, a requirement in simultaneous equation models. For example, land rights may be measured at a parcel level, while adoption of livestock technologies might be a farm level variable. Similar difficulties have been noted in developing analytical methods for examining the effect of land titling (parcel level) on crop productivity (field level) or use of credit (farm level) (Place and Migot-Adholla 1998).

Notwithstanding the discussion above, there are some instances where simpler, non-econometric techniques are preferable. One is where investments show little variation in a plot or household level survey. Thus, econometric models for qualitative variables do not always work, nor are they appropriate. Sometimes simpler decision trees (diagrammatic descriptions of relationships among discrete choice variables) will be able explain a substantial proportion of the different outcomes. For example, it may be that nearly all sloped land is terraced while hardly any flat land is terraced. A simple decision tree can show the patterns of these recursive relationships more clearly and powerfully than can econometric results.

INTERPRETATION

When faced with a situation where the majority of technologies are not found to vary much, researchers may be tempted to aim their attention on those few that do lend themselves to further analysis. This is of course legitimate. However, when making conclusions, researchers must remember to re-examine the totality of investments. For instance, if property rights were found to impact on 1 or 2 types of land investments, but 5 other similar investments were found to be present on nearly all fields/farms, what is the appropriate conclusion? The role of property rights will be overstated if only those investments exhibiting variation across the observational units are considered.

Finding a statistically significant result on a property rights variable is not the end of the analysis. Evaluating the magnitude of the coefficient is the second step in ascertaining whether or not a variable has a significant impact on technology adoption. Since property rights variables will often be of a binary nature, the size of the coefficient will directly reflect the impact of observing or not observing the specific property rights variable.

Relating back to Section 1, the results should be interpreted in light of the objectives of the study. If the study is based on a stratified sample using adoption of the technology as a criterion, then this must be kept in mind when interpreting marginal impacts. For instance, the sample rate of adoption will be over-stated in such a purposeful sample and thus, so also will the marginal impact of explanatory variables.

One last point on interpretation is that it may be wise in some instances to interact property rights variables with others to improve understanding. For example, property rights impacts may manifest themselves in different ways in different circumstances. For example, rights of sale may only be important in peri-urban areas so interacting this property rights variable with another indicating peri-urban location or not can provide additional clarification as to the circumstances under which the property rights effect holds.

PROVIDING INPUT INTO POLICY DISCUSSIONS

The finding that property rights may impact on technology adoption does not necessarily suggest changes to the property rights systems. It may be much simpler and more effective to alter certain characteristics of the technologies to enhance their adoptability under existing property rights. There are other reasons to pause before making policy recommendations from such studies. While case studies may have direct policy relevance at the study site, wider policy relevance of the research depends on the ability to draw wider implications from the study. Do the conclusions hold for more aggregated spatial scales? Are the conclusions based on a comprehensive evaluation of the impacts of property rights or only on certain impacts (e.g. efficiency only or equity only)? These are critical for it must be kept in mind that there are costs associated with property rights change.

If properly done, useful recommendations can be made to policy makers who have influence at the study site(s). However, most researchers would hope that their results could have influence well beyond the boundaries of their study sites. Working against ease of extrapolation is that property rights systems are complex, influenced by varying customary practices, formal rules and institutions, and by hosts of intervention organizations, such as development agencies. Thus, types of land acquisition methods and rights over resources may be quite uniquely defined within local areas. To find basis for comparison and extrapolation, it may be necessary to find common characteristics of rights and acquisition methods. For example, what might be defined as renting may actually differ significantly from site to site. Components of the rental method of accessing land, such as the formalization of the agreement, duration, relationship between transactors, and payment and other considerations exchanged are the types of variables that can be used to reconcile types of acquisitions across sites. It may well be that one or more of these components of renting are more important for technology adoption, than the more aggregate and blunt 'renting' variable.

Because property rights systems are fundamental to the pursuit of economic growth, equity, and sustainability, studies that focus only on the property rights-technology adoption link are generally modest in their policy recommendations. Two aspects of policy implication analyses could be strengthened. First, it is often presumed that more incidence of a technology is better, but the links between technology adoption and the wider goals of economic growth, equity, and sustainability are not often clearly elaborated. Second, the sequencing of complementary property rights interventions or between property rights and other policy options are not usually explored. These extensions could add considerable policy value to research in this area.

6. DEALING WITH THE COMPLEXITY OF PROPERTY RIGHTS AND TECHNOLOGY ADOPTION

This review covered several conceptual and empirical aspects associated with the study of the relationships between property rights and technology adoption in smallholder agriculture. Most of the discussion stems from the most general point of the paper, that the study of property rights and their effects is very complex. There is complexity in conceptualizing the important aspects of property rights and, once defined, in measuring them. Further complications in the study of property rights and their relationships with technology adoption arise because the different reasons for undertaking such studies lead to different research methodologies. Finally, property rights are often dynamic and related to other variables, including technology adoption, so that the isolation and quantification of direct and indirect effects between property rights and other variables is complicated from an empirical point of view. This paper has briefly referenced a number of other studies that have attempted to deal with portions of this complexity. The main recommendation of this paper is that this body of research must be reviewed prior to the launching of new studies on property rights and their relationships with agricultural technology adoption.

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

02 *Assessing the Relationships between Property Rights and Technology Adoption in Smallholder Agriculture: A Review of Issues and Empirical Methods*, by Frank Place and Brent Swallow, May 2000.