From science to technology adoption: the role of policy research in improving natural resource management

Peter Hazell*, Stanley Wood

Environment and Production Technology Division, International Food Policy Research Institute, 2033 K Street, N.W., Washington, DC 20006, USA

Abstract

GCTE3 science seeks to predict the effects of global change on agriculture, forestry and soils. Better understanding the response of these ecological systems, it is argued, will enable society to better ameliorate, adapt to, and even benefit from, the forces of global change. The argument presented in this paper, however, is that the response of managed ecosystems can only be understood by treating likely human response to global change as an integral part of the research agenda. Linking science and policy research matters because the adoption of technologies for improved natural resource management, or of other interventions that scientific research may help design, is conditioned by socio-economic factors that policy research is better equipped to articulate.

The paper first discusses how natural resource management and technology adoption are influenced by policy factors. It then explores why science — including GCTE — research needs to be linked to policy research. The reasons include: (a) that understanding biophysical processes is necessary but insufficient to understanding the socio-economic consequences of global change; (b) that the design of interventions to ameliorate negative and foster positive change at a global scale depends on gauging the likely human behavioral responses to change; (c) that although global impacts arise from an accumulation of local changes, interventions are often best coordinated in an international forum where the interests of potential “winners” and “losers” can best be matched. Different (winner and loser) nations have different policy stances on the underlying promoters of change, e.g., population growth, carbon emissions, biodiversity loss, etc. Failure to understand the (often economic) incentives underlying the “business-as-usual” position of many countries can hamper progress, even if the scientific arguments are compelling.

The paper also assesses how best to link GCTE science research and policy research. Researchers need to be: (a) concerned at many scales, from local to global; (b) able to predict and allow for the influences of technical change; (c) able to model biophysical processes and behavioral norms and responses in an integrated way. Interactive models in which biophysical processes impact on human behavioral response and vice versa are increasingly required. Even where land use and socio-economic models are not formally linked, significant gains may be made from multidisciplinary approaches and information exchange that develop common scenarios under which biophysical and economic analyses are made separately, but at least in complementary ways.

Keywords: NRM; GCTE; Technology adoption; Policy factors; Bio-economic models

1. Introduction

Practically every GCTE3 document from the GCTE3 manifesto “The Work of GCTE Focus 3” through the 1998 Implementation Plan to the
announcement for this conference enshrine the belief — often as early as the second or third sentence — that “agroecosystems are already threatened. . . . by damage to soil and water resources through inappropriate technology”. Policy researchers would question the validity of this fundamental axiom of GCTE3 doctrine, which is rather like attributing traffic accidents to the poor design of motor cars. Certainly poor technology can be a contributing factor to car accidents. But cars, like natural resources, are managed by people (the “M” word in NRM), and people do not always behave as some scientists would have them do. People also have choices over the technologies they adopt. Thus, technology is often not even a “driver” variable — it is more typical that technology selection is a response conditioned by peoples’ needs and resources. The basic contention of this paper, therefore, is that technology choice and related human actions likely to determine the evolution of natural resource conditions cannot be properly understood through GCTE3 science alone, and that it is necessary to integrate that science with policy research.

There are three objectives of this paper. First, to review how policy factors affect NRM and technology adoption, and to illustrate this with some important examples. The maintained hypothesis is that new technologies are rarely sufficient in themselves, and it takes a combination of appropriate policies and technologies to achieve more sustainable land uses and land use patterns. Second, to show why many global change problems are only amenable to resolution at a policy level — while science is important in shaping the nature of the global change debate, the nature of international action more often lies in the hands of politicians rather than scientists. Third, to suggest some ways in which biophysical and policy research might be more effectively linked.

2. Policy factors that influence NRM and technology adoption

A number of papers presented at this conference, especially some describing land use modeling studies, demonstrate the linkages between policy and technology factors in determining farmers’ decisions about NRM and adoption of new technology. Four key policy factors warrant special attention.

2.1. Prices

Land use decisions are very responsive to a broad range of prices (such as of inputs, outputs and credit) since these largely determine the relative profitability of alternative uses of resources, including land. Short-term elasticities for crop area (i.e., the percent change in the area planted to a crop that results from a 1% change in its price) typically fall in the range 0.1–0.3. Thus, other things being equal, a 10% increase in the price of an individual crop may lead to a quick 1–3% increase in its planted area. The total area of cropland is much less responsive, since compensating changes in area among crops tend to minimize the aggregate area change. The key point, however, is that land use change (substitution) effects can be quite large, and that the price changes that follow a major adjustment in world markets, or a devaluation in a country’s currency, can have large and immediate effects on land use patterns. These effects can easily dwarf any short to medium-term changes in land use patterns brought about through technical change. Recent example of these price effects are the accelerated rates of deforestation in Indonesia as a result of the recent economic crisis, and the rapid expansion of cocoa area in Ghana following the policy reforms in the 1980s.

Prices are also important determinants of the attractiveness of adopting new technologies, as well as of long-term investments in the improvement and conservation of natural resources. Adoption and investment decisions in turn affect the potential for longer-term agricultural growth. Since prices are largely determined by a combination of macro, trade and sector policies, policy research has much to contribute in helping to create an enabling environment for the uptake of appropriate technology and NRM practices.

2.2. Local institutions

Many technology choice decisions are affected by local institutions, particularly the effectiveness of indigenous property rights systems and the local capacity for organizing and sustaining collective action for managing natural resources. Fig. 1 (taken from Knox McCulloch et al., 1998) plots increasingly secure property rights on the horizontal axis and increasing levels of collective action on the vertical axis. Some of
the most successful agricultural technologies lie close to the origin in this figure. For example, the benefits of high yielding cereal varieties (HYVs) — the lynchpin of the green revolution — could be captured within a single agricultural season, and hence did not require secure property rights. Indeed, even sharecropping tenants with single season leases were able to adopt. Nor did they require collective action; individual farmers could adopt regardless of what their neighbors decided to do. These features made adoption decisions relatively simple, and help explain why green revolution technologies were able to spread so quickly and widely despite considerable diversity in local socio-economic conditions; a case of pure science prevailing with little regard to socio-economic constraints.

But as resource degradation issues have gained greater public attention, and as research agendas have responded with an increased focus on the sustainable use of natural resources, local institutional issues have become much more prominent. Integrated pest management, e.g., requires that all farmers in an area work together; the technology does not work if some farmers continue to spray indiscriminately or if there is not adequate synchronization of planting dates. However, the returns are relatively quick, so secure property rights are less of an issue. For these reasons, IPM appears in the upper left corner of Fig. 1. In contrast, planting of trees on farms (agroforestry) is a long-term investment that requires secure property rights. But since trees can be planted by individual farmers regardless of what their neighbors do, then farm trees appear in the lower right-hand corner. But many other technologies for improved NRM require both secure property rights and effective collective action, and therefore appear in the upper right-hand quadrant. Watershed development, e.g., requires secure property rights because it involves long-term investments in check dams, land contouring and tree planting in water catchment areas, and it can only be successfully done if the entire community living within the relevant landscape is mobilized to support collective action. If these institutional conditions are not met, then the technology is not likely to be adopted and maintained, regardless of its profitability and scientific soundness.

Difficulties arise because institutions for property rights and collective action are rarely formalized in developing countries, and communities vary widely in their ability to organize and sustain such institutions on their own. Socio-economic research has much to contribute towards our understanding of local institutions, and the conditions under which they are likely to be effective. Without such knowledge, and a corresponding ability on the part of policy makers to intervene and to strengthen local institutions when necessary, many promising NRM technologies are not likely to be adopted. Unlike the green revolution, science research on NRM issues cannot cut so easily through socio-economic constraints.

2.3. Population density

One proposition made in the preceding discussion is that technology is typically a choice (endogenous) variable rather than an exogenous “driver”. This can be seen in the relationship between population growth and technological change in many rural communities. In the history of US and Western European agriculture, e.g., agricultural mechanization was only developed and adopted widely when the rural labor force migrated in large numbers to more lucrative jobs in industry, often sited near urban centers. Mechanization was a spontaneous response to the increasing scarcity of agricultural labor relative to land. The need for mechanization led to the required invention and its subsequent adoption (a good example of the old adage: “necessity is the mother of invention”). This process of “induced innovation” is well documented, and a significant example of it is given below.
At low initial levels of population, there is relatively little pressure on the natural resource base — and hence little or no degradation — and the annual income accruing to the community remains stable. But as population grows, and the same land use practices are intensified, degradation becomes more serious, and this in turn leads to a decline in the annual income that the depleting natural resource stock can provide. Degradation may be subtle at first; perhaps fallows are shortened to the point where declining soil fertility slowly reduces yields. But later the degradation may become more severe through overuse of the community’s common property grazing and forest resources, extension of cropping into steep hillsides causing soil erosion, and over extraction or pollution of the available water resources. As degradation continues, and the natural resource stock is further depleted, the community’s loss of income (the vertical distance between the initial income level and the reduced income with degradation) increases more sharply. With lower income and an increasing population, per capita incomes fall even more sharply, leading to worsening poverty and perhaps even more desperate use of natural resources. Without any significant change in the community’s technology use, the “downward spiral” pathway (A in Fig. 2a) leads to the eventual demise of the community.

So far it has been assumed that the technologies used by the community remain unchanged. But people are rarely this passive, and the induced innovation theory (Boserup, 1965) suggests that, over time, improved land use practices and farming technologies will be adopted (even developed when necessary) in order to contain — and perhaps even reverse — degradation and to increase the productivity of the natural resource base. This might require, e.g., activities such as contouring or terracing of sloping land, replanting of trees, integration of livestock to improve soil nutrient management, and perhaps the purchase of fertilizers and higher-yielding varieties, and the growing of more cash crops. But such activities are not costless. Inputs may have to be purchased and considerable amounts of local labor may have to be invested. Moreover, collective action may be needed to coordinate and maintain some of these investments, and to improve the management of common property resources. This in turn is costly in time, and requires scarce organizational skills.

Fig. 2a–c (based on Scherr and Hazell, 1994) conceptualize the incentives for rural communities to seek and apply new technologies to meet their needs as their populations grow. The horizontal axis of Fig. 2a plots the increasing population of a given community over time, and the vertical axis indicates the annual income accruing to the community from its available stock of natural resources. This income includes the value of all agricultural production, water use, building materials, firewood, bush foods, and any other items collected from within the community.
Fig. 2b shows the annualized cost of degradation (simply by redrawing the negative income loss portion of Fig. 2a as a positive cost), and this loss can now be compared with the likely costs of reversing the degradation, i.e., rehabilitating the productivity of the natural resource stock. As population increases, the form of the rehabilitation cost curve is conditioned by several factors. Firstly, the factors that create a downward influence on costs, such as economies of scale and specialization as the rehabilitation process takes hold. Furthermore, the effect of declining levels of total community income coupled with higher population exert a downward pressure on per capita incomes and hence labor costs, and tend to reduce the unit cost of rehabilitation. Against these pressures are the increasing magnitude of the degradation problem and the generally increasing trend in average costs over time as more complex rehabilitation measures are required. The degradation cost curve in Fig. 2b can now be superimposed by a rehabilitation cost curve of a form that embodies these conditioning factors. This rehabilitation cost curve is designed to represent, at any given level of population (or degradation), the annualized costs that would need to be incurred to (arbitrarily) restore the community income to its initial level. Fig. 2b then illustrates how, initially, the community has no incentive to fix degradation problems as rehabilitation costs exceed the cost of degradation. However, as population grows, and resource degradation worsens, a point will eventually be reached (point $P^*$ in Fig. 2b) beyond which the cost of improvement is less than the cost of the degradation, and the community will begin to make the necessary investments. There may be some lag before the benefits of the investments begin to show up in a reversal of the decline in annual income, but the induced innovation hypothesis suggests that, eventually, income will begin to increase and the community will move onto a new, upward-sloping pathway.

The above analysis has abstracted from some complexities. One is that different levels of rehabilitation investment could be made in order to achieve a given income level in different time frames, i.e., the level of investment influences whether recuperating the original level of income takes, say, 5 or 10 years. Furthermore, there are different ways in which natural resources could be restored that would provide the initial level of income, but none of those necessarily imply restoring the original level and mix of natural resource stocks, nor the same bundles of goods and services that the community derived from those original stocks.

In arresting and perhaps reversing the decline in productivity of its natural resource stocks, the community may first draw on local knowledge and indigenous technologies. Some neighboring communities may already be more advanced in their own development, and improved practices and technologies may simply be borrowed. But local farmers may also innovate on their own; as two of the pioneers of agricultural economics observed almost a century ago: “every farm is an experiment station and every farmer the director thereof” (Warren and Livermore, 1911, p. 385). Adoption of local and indigenous technologies and farming practices may be sufficient to restore the initial productivity of the resource base, and hence the initial annual income of the community, leading to a pathway like B in Fig. 2c. But since there are now many more people in the community, simply restoring the initial level of community income would result in lower per capita incomes, and Fig. 2c also shows the level of total income required at any population level simply to maintain per capita incomes equal to their initial level ($I_0/P_0$). Additional technologies and investments would then be needed to raise the community’s annual income to higher levels than previously experienced, i.e., to put the community on a pathway such as C in Fig. 2c. Indigenous technology and farmer invention is unlikely to be sufficient for this purpose, and there will be a growing need for new productivity enhancing technologies from outside. This need will increase as the population size continues to grow and the community has to move even further up pathways like C.

This framework is very useful for thinking about the dynamics of technology needs within rural communities and for suggesting how scientific research may best help meet those needs. Not only does the science need to be relevant and timely, but also cost-effective. Communities that are still in their early stages of development, and which lie to the left of the intersection of their degradation and rehabilitation cost curves (point $P^*$ in Fig. 2b), will have very little incentive to invest in and adopt improved technologies and NRM practices. Unless heavily subsidized, attempts to transfer improved technologies are not likely to be successful in such communities. This is likely to be true for both the transfer of specific technologies and for attempts (perhaps by NGOs) to organize communities for
collective action for improved NRM. Once communities reach their intersection points, then incentives for technology adoption and improved NRM begin to become attractive. But at first, only low-cost investments are likely to be undertaken, perhaps drawing on local knowledge and practices, and inspiring simple inventions by local farmers themselves. There may be little payoff from new technologies from outside at this stage, although outside help in organizing relevant collective action may sometimes be worthwhile. But once communities start moving up pathways like B and C, then external technologies and inputs need to play an increasingly important role. Moreover, their availability and successful transfer will largely determine whether communities become trapped on pathways like A, implying a continuing decline in per capita income, or whether they can break through to pathways like C and grow to become prosperous communities. The framework provides various insights of relevance for science and technology development, but the most important is that rural communities in developing countries are dynamic entities that have their own changing needs for new technologies and NRM practices. Science research will be useful only to the extent that its outputs are synchronous with those changing needs and can offer benefits that exceed adoption costs. Policy research can help identify the technology needs of rural communities, and provide guidance on appropriate research and extension priorities.

2.4. Environmental externalities

Environmental externalities arise whenever there is a mismatch between those who degrade resources and those who bear the consequences. For example, a farmer whose activities pollute a stream with pesticides or silt causes problems downstream — such as contamination of drinking water, siltation of dams and irrigation systems — that can be costly to others. The fundamental problem is that since those who cause externalities (sometimes called “offsite” costs) do not bear the costs of their actions, they have little or no incentive to modify their behavior. On the other hand, those who bear the costs have every incentive to fix the problem, but usually have little or no effective means to do so. The consequences of such externality problems are often more apparent in developing countries where governments have little effective capacity to intervene through taxes or regulatory policies. Other examples of environmental externalities include excessive deforestation, mining of water, and the overuse of fisheries, rangelands, and other common property resources.

Since there is a fundamental mismatch between incentives and consequences it becomes easy to explain why many obviously appropriate NRM practices and technologies are not adopted, and why most externality problems are very difficult to resolve. Unless effective mechanisms can be found for resolving externalities, many environmental problems will likely continue to remain beyond the reach of technological solutions. Again, complementary policy and science research are essential ingredients in helping to resolve these problems.

This section concludes by reiterating that policy research can make important contributions to understanding how socio-economic “drivers” affect the types of technologies and NRM practices that farmers and communities will be likely to adopt, and it can provide guidance to policy makers on how to develop more enabling economic environments for the sustainable management of natural resources.

3. Why many global change problems require policy solutions

The relevance of policy research for influencing global change should be apparent from the previous discussion. But two areas are emphasized in which policy solutions are particularly important and where politicians, not scientists, will play the major role in dictating the nature of global responses to change.

The first issue is again related to environmental externalities, but this time involving regional or global externalities — those that affect many countries. Global climate change is a clear example in which total greenhouse gas emission is influenced by such things as the rate of energy consumption and deforestation in individual countries. Those rates of resource use are driven by national needs and interests (as well as the capacity of countries to regulate — or otherwise influence — the rate at which resources are used), but the consequential costs that arise through global climate warming are borne by all countries. Other examples include the loss of biodiversity and
important conservation sites, desertification, ozone emissions, and the degradation of global fisheries. In each case, the “polluters” and “polluted” are independent and sovereign countries, often separated by great distances, and resolving such problems involves negotiation in the international arena. Science has a central role to play in informing the debate and in defining — perhaps even lobbying for — alternative solutions, but ultimately global responses (the sum of the national responses mediated through international fora) lie in the hands of politicians and diplomats. Policy research likewise can help inform the debate but, even though such research often addresses the concerns of policymakers more directly, it cannot always lay claims to greater sway over the agreements that politicians finally make.

The second issue is that of growing resource scarcities, and particularly scarcities that are leading to greater competition between countries. In this century, many wars have been fought over oil and minerals. In the next century, wars may also be fought over water, particularly in arid parts of the world like the Middle East and North Africa. Science and policy research can make important contributions towards increasing the efficiency of use of scarce resources, and hence in deflating some of the evolving competitive pressures. But science research probably can do little to reduce countries’ perceived rights or claims over key resources, and this problem falls clearly within the political domain.

4. How to link GCTE and policy research?

Research aimed at understanding and improving NRM necessarily involves studying people and their behavior and hence calls for multidisciplinary approaches. While multidisciplinary research is not easy, it is essential if better bridges are to be built between good biophysical and good social science.

People are indeed messy to study, often seeming unpredictable and irrational as individuals. But as with any species, much greater regularity in behavior can be observed at the group level, or in the behavior of group means. The agenda of GCTE3 requires that predictions be made about how natural resources will be managed under different assumptions about global change. This requires an ability to model how peoples’ behavior in managing natural resources contributes to global change. It also requires an ability to model how people will change their management practices in response to global changes once they occur. Such a perspective suggests it is better to build less than perfect scientific models that include human behavior and to make predictions that are approximately right, than to build pure scientific models whose predictions are precisely wrong. Fortunately, the social sciences (and particularly economics) have made good progress in recent decades in modeling some relevant aspects of human behavior.

In approaching this issue, important questions arise about the scale and precise nature of the dominant NRM issues to be studied in an integrated way. Clearly GCTE research that is focused on improved scientific understanding of the response of basic biophysical processes to change (e.g., transpiration, soil particle movement, vegetation patch dynamics and so on) need not be related to policy research. But as soon as research on change at scales of the plot level and above (e.g., farm, landscape, and watershed) is considered, policy related variables inevitably come into play because of the role of human intervention in determining responses. However, there are still questions regarding the scales at which policy research might best complement science research given different types of NRM problems. For example, while climate change might be best addressed through global (policy related) fora it is not clear that the same level would be most appropriate for, say, biodiversity or water resource issues. In these cases other spatial foci such as ecosystem units and watersheds, respectively, may be more appropriate for both science and policy research since these are more likely to be the spatial groupings to which interventions might be targeted most effectively.

Furthermore, where the actual spatial configuration of change is important, such as with the loss of habitats, refuges and wildlife corridors, or as in the design of new integrated pest management strategies for large areas, the use of such research tools as geographic information systems (GIS) might be particularly appropriate. While the biophysical sciences have long recognized the utility of a spatially referenced framework for their own research, this is a new and exciting tool for policy researchers. A GIS also provides a very powerful framework for supporting multidisciplinary research of the type proposed here. It does this
through its capacity to organize and integrate a very broad range of data from different sources nested at different scales, as well as containing powerful functions for juxtaposing biophysical and socio-economic data in map formats that often provide new and informative data insights (Wood et al., 1999).

In terms of formally linking science and policy research at the modeling level, there are at least three ways in which human behavior can be incorporated into science models of NRM.

The first is a minimalist approach that assumes human behavior is passive and unchanging, even in the face of significant global change. One sees this approach in some of the land use modeling papers presented at this conference where fixed transition probabilities (or Markovian matrices) are used to predict the conversion of land from one use to another. Given an overwhelming body of evidence showing that people do adjust their NRM decisions to changing circumstances, it is hard to be very optimistic about the value of such an approach.

A second approach is to estimate statistical models of human behavior, and to incorporate these into science models. Regression analysis is often used for this purpose, and several papers at this conference show how land use and technology adoption can be predicted with regression equations that include a number of relevant biophysical and socio-economic explanatory variables on the right-hand side. Some of these biophysical variables can in turn be linked to predictions from science models. This is a useful approach for some purposes, and it is particularly appealing to some scientists because few explicit assumptions need to be made about how people behave. The approach has greatest value for analyzing more aggregate relationship for groups or regions, and is not an efficient way of using detailed micro-level data. Also, because the model coefficients are based on the observed variation in the underlying sample, it can be misleading to make predictions for new scenarios that require significant extrapolation.

The third and most promising approach is that of bio-economic modeling. These models confront the behavioral problem head-on and make very explicit assumptions about how people behave with respect to managing their resources. The basis is an economic model describing the decision problem of a household or community, with a relevant objective function (usually income, or risk-adjusted income) that is maximized subject to a set of constraints. The latter typically include seasonal constraints on resources such as land, labor, capital, and machinery and building capacity; agronomic constraints such as fertilizer–yield relationships, crop rotations and cropping restrictions on specific land types; behavioral constraints such as home grown food requirements, risk behavior, and ability to borrow. Activities include cropping and other land use and technology decisions, use of inputs like fertilizers, hiring and selling labor, leasing land and machines, borrowing credit, purchase or sale of crops and foods, and so forth. These economic models are usually solved through mathematical programming methods like linear programming, and have been used successfully by agricultural economists for about 40 years to model farm management and NRM problems (see, e.g., Hazell and Norton, 1986). Continuing advances in computer software and solution procedures are enhancing our capacity to build ever more realistic models. For example, features such as nonlinear constraint sets, dynamic optimization, adaptive decision making in response to risk events, and multiple objective functions, which previously led to exceptionally large or difficult problems can now be handled with relative ease.

The new “bio” element of the approach is the growing capacity to incorporate bio-physical modules that can track key NRM variables like soil nutrient balances, soil erosion, rangeland condition, groundwater levels and quality, and so on. These variables can be tracked as “stocks” in the model, with feedback effects on yields as stocks are depleted. For example, crop yields can be specified as functions of the available soil phosphate such that yields begin to decline when the stock of available soil phosphate falls below a given threshold (Barbier and Hazell, 1999). These feedback effects can be handled through a recursive approach that involves updating the stock values in a relatively short-term horizon model that is solved sequentially for a number of years, or they can be incorporated into multiperiod dynamic optimization models in which farmers are assumed to anticipate future feedback effects when they make current decisions. The latter approach assumes much more rational behavior than the recursive approach.

Bio-economic models are particularly appealing for NRM research (Ruben et al., 1998; Barbier and
Bergeron, 1998). They provide an excellent platform for multidisciplinary work because (a) they can be built from very micro-level data (even, e.g., incorporating the results of fertilizer treatment trials), and (b) because different science disciplines can contribute specific modules to the model. They can also be used to simulate the short and long-term consequences of a wide range of policy and technology changes, providing rich insights into the sustainability of farming and land use systems over time. Bio-economic modeling has already become a tool of choice among many CGIAR researchers, and it is a particularly promising approach that the GCTE3 group should consider.

5. Conclusions

Whether or not to integrate GCTE science research with policy research should no longer be an open question. Integration represents the most effective means by which GCTE researchers can make their NRM-related results accessible to, and impact on, decision-makers. Furthermore, funders increasingly require research proposals to give explicit attention to the likely socio-economic impacts of research. Donors such as the Global Environmental Facility (GEF) now expect that any research they fund will lead to appropriate policy changes and to the realization of significant global environmental benefits. As this paper maintains, this goal cannot be achieved through science research alone.

References


