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Innovation Systems Perspectives on Developing-Country Agriculture:
A Critical Review

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Abstract

Innovation systems perspectives on agricultural research and technological change are fast becoming a popular approach to the study of how society generates, disseminates, and utilizes knowledge. The innovation systems literature represents a significant change from the conventional, linear approach to research and development by providing an analytical framework that explores complex relationships among heterogeneous agents, social and economic institutions, and endogenously determined technological and institutional opportunities. Recent empirical work extends the innovation systems approach from studies of national innovation systems in industrialized-country manufacturing to developing-country agriculture, and shifts the emphasis from a unidirectional technology transfer approach to a more complex, process-based systems approach. This shift in perspective is appropriate for the study of developing-country agriculture because it captures the intricate relationships between diverse actors, processes of institutional learning and change, market and nonmarket institutions, public policy, poverty reduction, and socioeconomic development.

Early applications of the innovation systems framework to developing-country agriculture suggest opportunities for more intensive and extensive analysis. There is ample scope for empirical studies to make greater use of the theoretical content available in the literature, and to employ more diverse methodologies, both qualitative and quantitative. Further, there is room to improve the relevance of empirical studies to the analysis of public policies that support science, technology, and innovation, as well as to policies that promote poverty reduction and economic growth. This paper attempts to examine these issues with respect to recent applications of the innovation systems framework to developing-country agriculture, and suggests several ways to strengthen the mode of inquiry and quality of analysis.

The paper begins by tracing the literature on innovation systems from its roots in evolutionary economics and systems theory, followed by a review of recent applications to developing-country agriculture. This discussion is followed by the presentation of a model of an innovation system derived from a series of game theoretic and population game models in which heterogeneous agents interact and evolve through strategic patterns of behavior. The paper then reviews the strengths and weaknesses of recent applied work in developing-country agriculture and concludes with recommendations for improving analytical strength, relevance to public policy, and relevance to poverty reduction.

Key words: technological change, research and development

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1. Introduction

Innovation systems perspectives on agricultural research and technological change are fast becoming a popular approach to the study of how society generates, disseminates, and utilizes knowledge, and how such systems can be strengthened for greater social benefit. The more theoretical innovation systems literature represents a significant change from the conventional, linear perspectives on agricultural research and development (R&D) by providing a framework for the analysis of complex relationships and innovative processes that occur among multiple agents, social and economic institutions, and endogenously determined technological and institutional opportunities. The emerging body of empirical literature is equally significant in that it provides analysis of different forms of cooperation (e.g., research partnerships, knowledge networks, and industry clusters) among state and nonstate actors (e.g., public research organizations, private firms, and producer organizations) in various sectoral, spatial, and temporal contexts. Taken together, the innovation systems framework demonstrates the importance of studying innovation as a process in which knowledge is accumulated and applied by heterogeneous agents through complex interactions that are conditioned by social and economic institutions.

There is an acute need for this type of analysis in developing-country agriculture, as international and national agricultural research systems face significant institutional and organizational challenges that have resulted in insufficient funding, difficulties in training and maintaining good scientists, obstacles to accessing new scientific knowledge and technology, and other significant constraints (Pardey and Beintema, 2001; Byerlee and Fischer, 2001). An innovation systems approach can help policymakers, researchers, research managers, donors, entrepreneurs, and others identify and analyze new ways of encouraging innovation. It does so by offering greater insight into the complex relationships between diverse actors, processes of institutional learning and change, market and nonmarket institutions, public policy, poverty reduction, and socioeconomic development.

Yet there is little evidence to suggest that the application of the innovation systems framework to developing-country agriculture is, in fact, providing real solutions to many of today's challenges. While the framework is playing an important role in changing the mind-set of researchers and policymakers by encouraging them to consider new and unconventional actors and relationships, several methodological and analytical shortcomings are limiting its relevance to policy and policymaking processes, and thus to social welfare improvement in developing countries.

This paper begins in Section 2 with a brief overview of the literature on agricultural development and technological change, including a review of the seminal literature on innovation systems and its application to developing-country agriculture. Section 3 sets forth the conventional terminology used in the literature, followed in Section 4 by a model of an innovation system derived from a series of game theoretic and population game models in which heterogeneous agents interact and evolve through strategic patterns of behavior. The strengths and weaknesses of the innovation systems framework—and recommendations for improving the framework—are discussed in

Section 5 with respect to developing-country agriculture, followed by concluding remarks in Section 6.

2. The Innovation Systems Approach: A Literature Review

Early study of innovation can be traced to Adam Smith ([1776] 1993), who first noted the influence of innovation—new production techniques and new divisions of labor—on output and society. But it is the works of Ricardo (1821) that provide a useful starting point for a discussion of both orthodox (neoclassical) and heterodox economic perspectives on innovation and technological change in agriculture. Ricardo's analysis captured the fundamental challenges of agricultural production: land's diminishing marginal returns, and the importance of technology in shifting agricultural production possibilities. More importantly, his analysis introduced factor bias as a determinant of the impact of technological change on productivity, income, and welfare. Ricardo did this by distinguishing between two types of technology: that which "increases the productivity powers of the land" or that which "obtains its produce with less labor" (p. 54). The former described the land-saving techniques of production undertaken in early 19th-century England—crop rotation, water management, and intensive use of livestock manure to preserve soil fertility—that combined several inputs to increase output per unit of land. The latter described the use of improved agricultural tools and machines that substituted capital for labor, but, in the Ricardian schema, had no effect on land productivity. Here, Ricardo provided an early analytical framework for studying the form and nature of innovation and its impact on social and economic well-being.

Ricardo's analysis gave rise to further interest in the social and economic effects of technological change by such classical political economists as List (1841), Mill ([1848] 1965), and Marx ([1894] 1990). In fact, it is List who is credited with the earliest description of a "national system of political economy"—a precursor to the innovation system concept—in which production results not only from the activities of the firm but also from those social and economic institutions (e.g., education, infrastructure) that make production possible (Lundvall et al., 2002; Freeman, 1995). Leontieff (1941) further contributed with his celebrated input/output analysis that established an industry-level "system" approach to production used later by scholars to explain innovative processes.

But it was Schumpeter ([1934] 1961; 1939) who laid the cornerstone of the modern innovation systems approach. Schumpeter provided the first nuanced definition of technological change by distinguishing between invention, innovation, and diffusion. He added further nuance to the concept of innovation—defined as any addition to the existing body of technical knowledge or know-how that results in an outward shift of the production function and a downward shift of the associated cost curves—by distinguishing between product, process, and organizational innovation (1939, p. 87; [1934] 1961, p. 66; Blaugh, 1996, pp. 454–455).

But Schumpeter's real insights were in his analysis of the market and institutional conditions that generate innovation. In the Schumpeterian system, technological change results from the innovative activities of large firms that are afforded market power at the expense of short-term social welfare (Nelson and Winter, 1982). Innovation is thus endogenously determined by the behavior of the entrepreneur and his or her financiers, and by the institutions of private property, business traditions, and capitalist competition (Clemence and Doody, 1966, p. 47). Over the long run, technological change results from the continuous market entry of entrepreneurial agents and innovation processes that force older firms and production methods into obsolescence, thereby reallocating resources into new products and processes and reorganizing key aspects of the economy—prices, goods, credit, and so on—to support a new production regime (the "creative destruction," or Schumpeter Mark I model).[1] Movement from one state, characterized by a set of innovations and related institutions employed by society, to the next ultimately results in greater output for unchanged money incomes, interest rates, profits, and indebtedness. This implies an increase in society's control over real consumption, that is, lower prices and higher real incomes that represent economic growth. In sum, Schumpeter suggested that innovation results from the character of social and economic institutions, and that institutions change in response to innovation, that is, that the relationship between society and innovation is endogenously determined.

[1] A secondary Schumpeterian model, typical to more mature firms and industries, obtains from the accumulation of innovation and within-firm changes in the allocation of resources into new products and processes (the "creative accumulation," or Schumpeter Mark II model).

The innovation systems approach emerged in the mid-1980s as a neo-Schumpeterian perspective that drew significantly from the literature on evolutionary economics and systems theory. Evolutionary economists such as Nelson and Winter (1982), Dosi et al. (1988), Metcalfe (1988), and Andersen (1994) inform the innovation systems framework by emphasizing continuous and nonlinear processes of endogenously determined technological and institutional change, in contrast to the more conventional study of relative factor prices, exogenous technological shocks, and static equilibria. From systems theory, the innovation systems approach drew its emphasis on the study of the attributes and interactions among diverse elements of a set, how the properties and behaviors of each element influence other elements and the set as a whole, and how interdependence among the elements renders the set indivisible and thus analysis of a single element irrelevant (Caarlson et al., 2002).

A comprehensive description of the innovation systems approach was first set forth by Lundvall (1985) and applied to national comparisons of innovation systems by Freeman (1987). The concept was further elucidated in Dosi et al. (1988), Lundvall (1988, 1992), Freeman (1988, 1995), Nelson (1988, 1993), and Edquist (1997), with empirical applications focusing primarily on national industrial policy in Europe, Japan, and several East Asian countries that were experiencing rapid industrialization during the 1980s. Recent work in innovation systems has added new analytical dimensions, including the study of systems at different spatial (i.e., geographically determined) levels (Saxenian, 1994; Braczyk, Cooke, and Heidenreich, 1998; Fritsch, 2004), at different sectoral levels (Breschi and Malerba, 1997; Malerba, 2002), in different time periods

(Anderson and Teubal, 1999; Andersen, 2000, 2004), and in relation to a given technology set (Carlsson and Jacobsson, 1993; Carlsson, 1995, 1997). Application of the innovation systems approach has since been explored by the Organization for Economic Cooperation and Development (OECD, 1997) and its members (Arnold and Bell, 2001), the United Nations Commission on Trade and Development, the European Commission, and, more recently, the World Bank and International Monetary Fund (Lundvall et al., 2002).

Studies that use an innovation systems framework are recognized by their ability to analyze processes that are typically overlooked in the linear approach to R&D. Innovation systems studies often open the “black box” of innovation to analyze actors’ motives and behaviors; the institutions that shape these motives and behaviors; interactive, joint, and complementary processes of innovation; and the dynamics of institutional learning and change. They also provide analyses that extend beyond single industries or markets to capture a wider range of agents (public and private), interactions (competition, cooperation, and learning), institutions (social practices and norms), and policies (science, technology, trade, education, and investment) that condition agents’ interactions and responses to innovation opportunities. Further, they often provide analyses of policy design from the perspective of policy as a continuous process that adapts to institutional and technological opportunities presented by socioeconomic change and development (Metcalfe, 1995, 2000). This differs significantly from the neoclassical assumption that policy is the domain of fully informed social planners who reconcile social and private welfare within a system of rational maximizers.

But while insights from Schumpeter, evolutionary economics, and systems theory have contributed to the development of the innovation systems perspective, they have had little influence on the study of agricultural research and technological change in developing countries.[2] Theories of technological change in agriculture developed in the latter half of the 20th century have tended toward the Hicksian notion of innovation induced by relative factor scarcities, rather than the Schumpeterian system described above. By introducing relative factor scarcities and prices as the key determinants of innovation, Hicks ([1939] 1946) married the notion of innovation to the larger neoclassical framework. Thus, it is Hicks's work that gave rise to the modern theories of agricultural development and economic development posited most notably by Hayami and Ruttan (1971). Their work, in turn, gave rise to a dense literature on the role of public research systems in generating technological change in agriculture (Echeverría, 1990; Huffman and Evenson, 1993; Anderson, Pardey, and Roseboom, 1994; Alston, Norton, and Pardey, 1995; and Alston, Pardey, and Smith, 1999, among others), bolstered by studies

[2] Worth noting is the relative distance between the innovation systems approach and new institutional economics (NIE). The NIE approach provides insights into how agents engage in the production, diffusion, and utilization of knowledge and technology where markets fail or are otherwise incomplete. (For a survey of the NIE literature with respect to agriculture, see Kherallah and Kirsten, 2001.) The innovation systems approach, in contrast, emphasizes the study of complex nonmarket characteristics (organizational characteristics and capabilities, for example) as well as nonmarket interactions (interactive learning processes and feedback loops, for instance) and how they are embedded in systems and processes of innovation (Hall et al., 2003; Lundvall et al., 2002). Despite different areas of emphasis, some leading authors in the innovation systems literature contextualize their work using modes of analysis that are plainly drawn from NIE perspectives. For instance, Metcalfe (1997) examines innovation systems in the context of nonclearing markets for innovative activity; the influence of information asymmetries, property rights, appropriation externalities, indivisible capital investments, and nonrival/nonexcludable (public) goods in innovation markets; the effects of noneconomic forces such as culture, history, and path dependency; and the necessity of technology policy in preserving certain market inefficiencies so as to ensure greater innovative output.

on the successes of the Green Revolution (Lipton, 1989; Hazell and Ramasamy, 1991; and Hazell and Haddad, 2001, among others).

The primary focal point of this literature has been the public sector agricultural research organization, which, in effect, has translated into the study of how national agricultural research systems (NARS) effect technological change through a linear model of research, development, and extension. The NARS perspective recognizes the public-goods nature of agricultural research and the absence of market access or purchasing power among many agrarian agents, and thus places necessary emphasis on the role of the state in fostering technological change. Yet the NARS approach tends toward linearity in so far as the movement of knowledge is described as originating from some known source (the scientific researcher) and flowing to some end user (the farmer), with the assumption that social and economic institutions in which this process occurs are largely exogenous and unchanging.

A slightly more sophisticated approach is found in the agricultural knowledge and information systems (AKIS) perspective, which incorporates important concepts from the study of information and knowledge economics. The AKIS perspective highlights the linkages between research, education, and extension in generating knowledge and fostering technological change (Nagel, 1979; Röling, 1986, 1988).[3] More importantly, by focusing on the dynamics of dissemination through extension, the approach rectifies some of the conceptual gaps that had impeded analyses of how knowledge moves

[3] For a useful comparison of the NARS, AKIS, and the innovation systems approach, see Chema, Gilbert, and Roseboom (2003).

between researchers and end users.

The AKIS perspective, embedded as it is in the study of how knowledge flows between and among agents, is less linear than the NARS approach. Yet it may be argued that the perspective is limited in its ability to conduct analysis beyond the nexus of public sector research, university research, and extension services and to consider heterogeneity among agents, the institutional and historical context that conditions their behaviors, and the learning processes that determine their capacity to change and innovate. The innovation systems approach broadens the NARS and AKIS perspectives by focusing on the processes by which diverse agents engage in generating, disseminating, and utilizing knowledge, the organizational and individual competencies of such agents, the nature and character of their interactions, and the market and nonmarket institutions that affect the innovation process.

Yet the innovation systems approach is still nascent in the study of developing-country agriculture. Biggs and Clay (1981) and Biggs (1989) offer an early foray into the approach by introducing several key concepts—institutional learning and change, and the relationship between innovation and the institutional milieu in which innovation occurs—that become central to later innovation systems studies on developing-country agriculture. Later studies by Hall and Clark (1995), Hall et al. (1998), Johnson and Segura-Bonilla (2001), Clark (2002), Arocena and Sutz (2002), and Hall et al. (2002, 2003) introduce the innovation systems approach to the study of developing-country agriculture and agricultural research systems. Regional and national applications of the innovation systems approach include Sumberg (2005), Roseboom (2004), Chema, Gilbert, and Roseboom (2003), Peterson, Gijsbers, and Wilks (2003), and Hall and Yoganand (2004) Sub-Saharan Africa; Vieira and Hartwich (2002) for Latin America; and Hall et al. (1998) for India. Several studies focus on the institutional arrangements in research and innovation—for example, Hall et al. (2002) on public-private interactions in agricultural research in India; Porter and Phillips-Howard (1997) on contract farming in South Africa; or Hall et al. (1998), Allegri (2002), and Kangasniemi (2002) on producers' associations in South Asia and Sub-Saharan Africa. Other studies focus on technological opportunities, such as Ekboir and Parellada (2002) on zero-tillage cultivation.

These studies are distinguished from the many other works on agricultural R&D because they embed analyses of innovation within the wider context of institutional change and change processes. Further, they offer some answers to certain research questions that the conventional R&D literature is often unable to address. For example, Ekboir and Parellada (2002) offer a detailed look into the social and economic changes that encouraged the diffusion of zero-tillage cultivation in Argentina, a process that resulted from a complex series of events and interactions among farmers, farmers' organizations, public researchers, and private firms. Hall et al. (2002) provide an in-depth study of the institutional and organizational learning processes that stimulated the diversification of agricultural research financing in India to include new actors (e.g., medium-sized firms and producer cooperatives) and new modalities (e.g., contract research, public-private partnerships). Clark et al. (2003) unlock the mysteries of a successful donor-funded project in postharvest packaging for small farmers in Himachal Pradesh, India, by studying the institutional learning and change processes that were incorporated into the project design. The common thread in all these studies is the emphasis placed on the role of diverse actors and interactions within complex systems of innovation, and the institutional context within which these processes occur.

3. Key Terms and Definitions

To better understand the conceptual framework offered by the innovation systems approach, we provide here a summary of conventional terms and definitions. First, an *innovation* is defined here as any new knowledge introduced into and utilized in an economic or social process (OECD, 1999). Second, an *innovation system* is defined as a set of interrelated agents, their interactions, and the institutions that condition their behavior with respect to the common objective of generating, diffusing, and utilizing knowledge and/or technology. Third, *agents*—comprising individuals and firms as well as public institutions and nonstate actors—constitute the principle operating components of the system. Agents typically enter not as rational maximizers responding to price signals, but as strategists, responding to other agents' behaviors and their institutional context.[4]

[4] Carlsson et al. (2002) vest agents with four different types of capabilities: selective, organizational, functional, and learning. From a strict economic perspective, these capabilities are difficult to distinguish since each is reduced to the simple question of whether the agent is making rational decisions in his or her effort to efficiently allocate scarce resources for innovation. Having said that, the subtle differences between different types of capabilities are meant to capture the robustness, flexibility, and responsiveness of agents in a dynamic innovation system, and therefore may merit further examination.

In much of the innovation systems literature, the firm constitutes the focal agent of inquiry. But in the system's application to developing-country agriculture, the focus can be extended to a wider variety of agents engaged in the generation, dissemination, or use of knowledge or technology (see, inter alia, Clark, 2002). The primary focal agent in the literature is often the public sector research system: national research organizations, extension systems, state marketing agencies, institutes of higher learning, and international research centers. However, private firms are also increasingly important focal agents, and may include multinational and national agribusiness firms; small and medium enterprises engaged in agroindustrial processing, marketing, and distribution; industry associations; and individual entrepreneurs. Civil society organizations are also important focal agents and include producer/farmer associations, nongovernmental organizations, consumer groups, and other types of community or solidarity groups. And, finally, agrarian agents are also critical focal agents; these include farmers, agricultural laborers, farm households, and rural communities that are engaged not only in the utilization of knowledge but in its production and diffusion as well.

Next, consider the role of *knowledge* in an innovation system. Knowledge can be categorized in many different ways. Knowledge may be classified according to form—for example, as scientific/technical knowledge or organizational/managerial knowledge, as well as codified/explicit and tacit/implicit knowledge (Hall et al., 2002). Knowledge may also be embodied in some good, service, or technology; or it may be distinct, disembodied, and complementary. Knowledge may be further characterized by its degree of accessibility and accumulation over time or among agents, depending on an agent's capacity to exchange, learn, and absorb. Since there is no limit to the taxonomy of knowledge, we assume that these classifications suffice for the present purposes.

Next, consider the *sources of knowledge* in an innovation system. Knowledge sources may be external to a given agent within an innovation system—for example, a scientific journal article documenting a laboratory breakthrough, or a neighbor who introduces one to a new way of achieving something. Alternatively, the knowledge source may be some internal process—for example, the reorganization of human and scientific resources within a firm to improve efficiency (Malerba, 2002). Knowledge may also derive from the conventional providers of advanced research: public research organizations, private laboratories, and universities. Yet it may also emerge from the practices and behaviors of individuals, households, and civil society organizations (Clark, 2002). In sum, knowledge sources are not simply those entities producing cutting-edge science; rather, they are any entities that introduce new knowledge into a social or economic process.

Next, consider the different *interactions* or relationships between and among agents in an innovation system. Interactions are numerous and varied, and include such relationships as spot market exchanges of goods and services that embody new knowledge or technology; costless exchanges of nonrival, nonexcludable knowledge made available in the public domain; long-term, durable exchanges that incorporate complex commitment mechanisms and related transaction costs; collusive arrangements among oligopolistic firms; and hierarchical/command structures that govern the exchange process. Equally important are those interactions among individuals and organizations that are characterized by learning and feedback processes. The study of how individual agents structure their strategic interactions is what gives the approach its definitive *systems* perspective.

It is worth noting here the centrality of *cooperation*—incompletely specified exchange (nonmarket) relationships that allow for opportunistic behavior by agents involved in the exchange—in the context of an innovation systems framework (Fritsch, 2004). Cooperation, though only one of several forms of interaction, is one of the key behavioral aspects of agents in an innovation system and is conditioned by the institutions that promote or impede it. This concept is particularly relevant when studying learning processes or relationships that blur the traditional roles of distinct actors—for example, partnerships between public and private research entities (Pray, 2001; Hall et al., 2002; Spielman and Von Grebmer, 2004).

Next, an innovation system includes those *institutions* that affect the process by which innovations are developed and delivered—the laws, regulations, conventions, traditions, routines, and norms of society that determine how different agents interact with and learn from each other, and how they produce, disseminate, and utilize knowledge. These are the factors that determine the efficiency and stability of cooperation and competition, and whether agents in an innovation system are able to interact so as to generate, diffuse, and utilize knowledge. An institution may be no more explicit than a traditional tendency toward (or away from) informal entrepreneurial behavior in agrarian society, such as farmer exchanges of seed and other planting materials; or it may be more codified in the laws that govern how private, knowledge-based firms are established, licensed, and taxed, and the extent to which such firms can appropriate the rents from innovation.

Finally, an innovation system requires some unit of study or *dimensions of analysis* to delineate its boundaries (Metcalfe, 1997; Carlsson et al., 2002). As mentioned above, analysis may focus on the spatial (local, national, and regional economic or geopolitical units), the sectoral (manufacturing, agriculture, or any subsector thereof), or the technological (for example, information and communications technology, agricultural biotechnology, or other distinct technology sets). Further, analysis may focus on the material, such as a particular good or service that forms the focal point of a given commodity value chain. Analysis may also focus on a temporal dimension by studying how relationships among agents change over time as a result of knowledge transfers, feedback mechanisms, institutional learning, decision rules, adaptive behavior, and organizational transformation (Nelson and Winter, 1982). In short, a diversity and wealth of analytical dimensions fall within the innovation systems framework.

4. An Innovation System Model

Game theoretic modeling based on emerging work in evolutionary economics offers some insight into the value of the innovation systems framework. The models described below illustrate the spontaneous processes of social self-organization and the ways in which public policy and organizational structures can affect these processes. This perspective differs significantly from the neoclassical approaches to constitutional design and benevolent social planning: in an evolutionary approach, aggregate social outcomes are not the summation of individual maximizing behavior; rather, they are the result of individual behavior conditioned by the behavior of others and by the institutional landscape that conditions these behavior patterns.

The evolutionary model employed below derives from the biological population models described by Maynard Smith (1982) but substitutes for the intergenerational selection of biologically inheritable traits the selection of socioeconomic behaviors, both idiosyncratic and intentional, over time. The approach is described in detail by Nelson and Winter (1982) and pursued further by Andersen (1994, 2000, 2004), who models an innovation system with Schumpeterian characteristics to describe the strategic decision-making processes of diverse agents who cooperate, compete, or otherwise interact over time.[5]

A Schumpeterian game theoretic model similar to that described by Andersen (2000) is configured as follows.[6] First, the model is set up with the standard attributes of a noncooperative game: several agents ("players") pursue different behaviors ("strategies") that obtain different outcomes ("payoffs"). Second, the model is initially configured as the classic hawk/dove game. Intuitively, when a hawk and dove meet, the dove is severely injured by the hawk's aggressive nature; when two hawks meet, they are

[5] For a comprehensive study of different strategic interaction models, see Gintis (2000).
[6] The succession of models presented here is only loosely based on Andersen (2000). Several changes have been made to the definitions of (and intuition behind) the agents' characteristics, their payoff structures and behavior, and their implications within an evolutionary system.

both severely injured because of their equally aggressive natures; and when two doves meet, they both fare well because of their peace-loving nature.

The hawk and dove strategies are respectively renamed Innovator *(I)* and Adaptionist *(A)* to capture the Schumpeterian nature of the game described here. In this game, an Innovator might be an actor who possesses and transforms knowledge into a functional technology. For instance, an Innovator might be a research-based firm or a highly entrepreneurial individual. An Adaptionist might be an actor who applies such knowledge to the production of some good or service. Thus, an Adaptionist might be a small-scale farmer or a rural entrepreneur. These descriptions provide an appropriate starting point for modeling a simple innovation system because they represent a set of agents that engage in interactions (exchanges) that are subject to coordination failures caused by, say, contracts for appropriating rents from innovation that are difficult to enforce or otherwise incomplete.

We begin with a one-off, static version of the game and describe the payoffs as follows. When a player choosing an Innovator strategy meets another player choosing the same Innovator strategy, the duplication of innovative effort implies that they must equally divide the value of the appropriable benefits $(v / 2)$ of their innovative activity and equally divide the transaction costs associated with the meeting $(c / 2)$. These transactions costs—say, expenses incurred in the process of protecting, securing, or obtaining rights to appropriable innovation rents—are prohibitively high $(c > v)$, implying that the payoffs are detrimental to each party. However, when an Innovator meets an Adaptionist, the Innovator appropriates the full value of its innovative activity without cost.

Conversely, when an Adaptionist meets an Innovator, the Adaptionist realizes no benefit since the Innovator appropriates the full value of its innovative activity, as mentioned above. When an Adaptionist meets another Adaptionist, however, both share the benefits of the innovation equally, less any transactions costs incurred in the meeting *(z)*. We assume that an Adaptionist's costs are neither prohibitive nor greater than an Innovator's costs $(z < c)$.

These strategies can be presented in a strategic (or normal) form model as shown in Table 1. Player 1 is represented by the row strategies and payoffs. Player 2 is represented by the column strategies and payoffs. Note that the payoffs shown in Table 1 are those of Player 1 (the "row" player), while Player 2's payoffs are found symmetrically across the diagonal.

Table 1: Payoff Matrix, Innovator/Adaptionist Game

	Innovator	Adaptionist
Innovator	$(v - c) / 2$	v
Adaptionist	0	$(v - z) / 2$

Numerically, by assigning values such that v = 3, c = 5, and z = 1, consistent with the inequalities described above, the payoff matrix is as in Table 2.

Table 2: Numerical Payoff Matrix, Innovator/Adaptionist Game

	Innovator	Adaptionist
Innovator	*–1*	*3*
Adaptionist	*0*	*1*

The outcomes of a one-off interaction suggest that there is no dominant strategy to this game: we cannot simply predict a single strategy that each player will (or will not) choose. The outcomes shown here are two Nash equilibria, indicating two self-evident outcomes in which neither player can gain without making the other worse off, or in which all players' strategies are best responses to the other available strategies. This implies that neither player has an incentive to alter his or her strategy given the strategies adopted by others: it is always better to be an Innovator when facing an Adaptionist, and always better to be an Adaptionist when facing an Innovator. Both equilibria are Pareto optimal in the sense that the strategic responses leave each player better off than had he or she pursued some other strategy. These outcomes are consistent with the solutions that obtain from the standard payoff (π) structure of a hawk/dove game, namely

$$\pi(I,A) > \pi(A,A) > \pi(A,I) > \pi(I,I) \tag{1}$$

Next, consider this game within the context of an entire population comprised of Innovators and Adaptionists. Here, Innovators and Adaptionists interact randomly on a frequency-dependent basis within a system; that is, they meet up with one another based on the proportion of Innovators $(\alpha\ 0\ [0, 1])$ and Adaptionists $(1 - \alpha)$ present in the system. Payoffs to the Innovator are the sum of the payoffs of interacting with another Innovator and another Adaptionist, subject to the probability of each interaction occurring within the system, or

$$\pi(I,\alpha)=\alpha\left(\frac{v-c}{2}\right)+\left(1-\alpha\right)v \tag{2}$$

Similarly, the payoffs of the Adaptionist strategy are

$$\pi(A,\alpha)=\alpha(0)+(1-\alpha)\left(\frac{v-z}{2}\right) \tag{3}$$

Equating the payoffs of the two strategies and solving for α yields

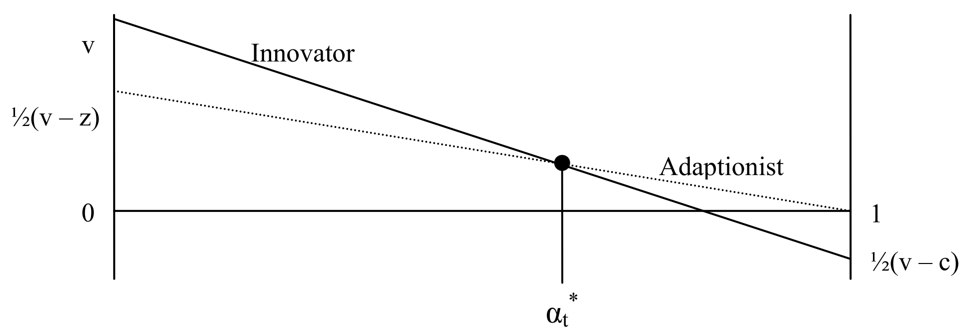
$$\alpha^{*}=\frac{v+z}{c+z} \tag{4}$$

where α^* represents the equilibrium distribution of Innovators and Adaptionists in the system, represented graphically in Figure 1. Using the numerical payoffs given in Table 3, $\alpha^* = 2/3$.

Intuitively, the institutional context (the payoff structure) within which this population evolves obtains a stable equilibrium in which the two types of behaviors (Innovator and Adaptionist) are able to coexist. Using the numerical payoff structure, the system is characterized by a population consisting of two-thirds Innovators and one-third Adaptionists.

Next, consider a dynamic model of this game in which the proportions of Innovators and Adaptionists change over time as agents update their behavior based on learning and positive feedback processes between time periods *t* and *t +1.* Assume that

Figure 1: Innovator/Adaptionist Game



some small proportion of the agents (ω) choose to deviate from their strategy and experiment with new strategies based on what they learn in interactions with other agents. If the payoffs of such a deviation are greater than the payoffs of their existing strategy, then they will change their strategy—Innovators will become Adaptationists and Adaptationists will become Innovators.

More formally, a change in the proportion of Innovators between *t* and *t +1* will result when the payoffs to members of a deviating group are greater than the mean payoffs in the system. By expressing the mean payoff as

$$\bar{\pi} = \alpha_t \pi(I, \alpha_t) + (1 - \alpha_t)\pi(A, \alpha_t) \tag{5}$$

then the change in the proportion of Innovators between *t* and *t+1* is equal to

$$\Delta\alpha = \omega\alpha_t \left[\pi(I, \alpha_t) - \bar{\pi}\right] \tag{6}$$

This equation is commonly referred to as the replicator dynamic, or the process through which the frequency distribution of those strategies with higher payoffs increases to an asymptotically stable distribution. In intuitive terms, the replicator dynamic describes the process by which individual behaviors and practices are copied and disseminated (or rejected and rendered extinct) throughout a population via a process of repeated interaction between agents and conditioning by institutional context.

The asymptotically stable distribution obtained from this process is referred to as an *evolutionarily stable equilibrium*—analogous to a Nash equilibrium in the one-off game described above—and is obtained where there is no change in the proportions of Innovators and Adaptionists in the system, that is, where

$$\frac{d\alpha}{dt} = 0 \tag{7}$$

In this model, three such equilibria are possible: two are found where the system is comprised exclusively of Innovators or Adaptionists ($\alpha = 1$ or 0). But these solutions are inherently unstable: any deviation within the system *($\omega > 0$)* will cause movement away from these equilibria. Moreover, these solutions are uninteresting in so far as a homogeneous population tells us little about innovation and evolution. However, the third possible equilibrium is of interest: this is the point at which the payoffs of each strategy are equal, that is

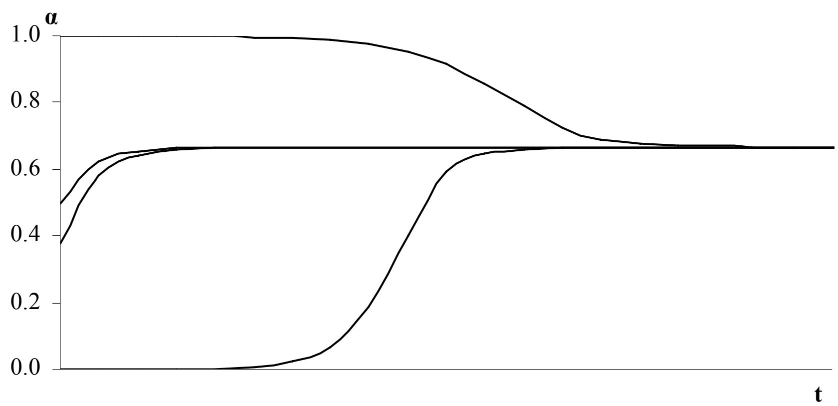
$$\pi(I,\alpha_t)-\pi(A,\alpha_t)=0 \tag{8}$$

Given the payoffs set forth in the model, this equilibrium solution is evolutionarily stable because any agents choosing to deviate will find that the payoffs of a change in strategy are unfavorable, thus causing them to return to the equilibrium distribution, or

$$\frac{d[\pi(I,\alpha_t)-\pi(A,\alpha_t)]}{d\alpha_t}=-\left(\frac{2v+c-z}{2}\right)<0 \tag{9}$$

Thus, the point at which this condition is met (for $\alpha \neq 1,0$) is an evolutionarily stable system profile. A graphic representation of the trajectory of the system's replicator dynamic shows an asymptotically stable outcome (Figure 2). Using our numerical example again, a stable population is made up of two-thirds Innovators and one-third Adaptionists.

Figure 2: Replicator Dynamic of an Innovator/Adaptionist Game



Next, consider a model of an innovation system comprised of Innovators *(I)*, Adaptionists *(A)*, Complementors *(C)*, and Imitators *(M)*. A Complementor might be described as a small-scale innovator whose marketable product depends on that of the primary Innovator. An Imitator might be more like a pirate, realizing the full value of appropriable benefits with only negligible costs. Through this model, we begin to capture some of the complexities inherent in a more realistic system, and present the possibility of multiple evolutionarily stable equilibria.

The model's payoff structure between Innovators and Adaptionists is as described above. But the additional interactions posed by this game warrant further explanation. First, when an Innovator meets a Complementor, the Innovator appropriates the full value of its innovative activity without cost, while the Complementor generates its own additional, appropriable value from the meeting *(v)* less its own costs *(r)* that are assumed to be greater than those of an Adaptionist but less than those of an Innovator $(c > r > z)$.

When a Complementor meets either an Adaptionist or another Complementor, the two equally divide whatever value is generated in their meeting. Necessarily, since neither agent creates much value independently, the benefits they divide are relatively small and, depending on the cost structure, possibly negative. Finally, when an Imitator meets any other agent, the Imitator appropriates the full value of the Innovator's innovative activity with only nominal cost *(s)*. We assume that the Imitator faces the lowest cost structure, such that $c > r > z > s$. Table 3 describes this payoff structure.

Table 3: Payoff Matrix, Innovator/Adaptionist/Complementor/Imitator Game

	Innovator	Adaptionist	Complementor	Imitator
Innovator	$(v - c) / 2$	v	v	0
Adaptionist	0	$(v - z) / 2$	$(v - z) / 2$	0
Complementor	$v - r$	$(v - r) / 2$	$(v - r) / 2$	0
Imitator	$v - s$	$v - r - s$	0	0

Numerically, assuming $r = 2$ and $s = ½$, the payoffs are as shown in Table 4.

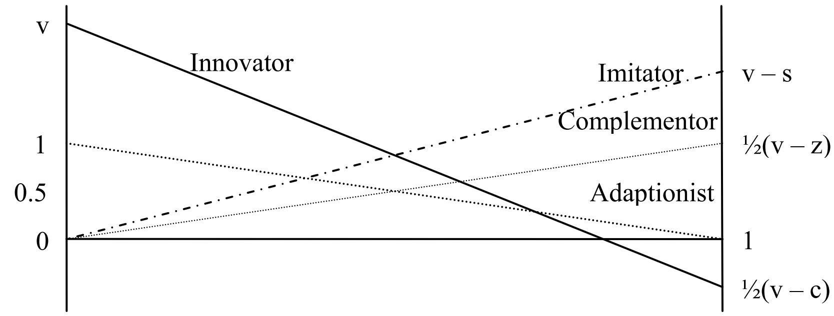
Table 4: Numerical Payoff Matrix, Innovator/Adaptionist/Complementor/Imitator Game

	Innovator	Adaptionist	Complementor	Imitator
Innovator	*–1*	*3*	*3*	*0*
Adaptionist	*0*	*1*	*1*	*0*
Complementor	*1*	*½*	*½*	*0*
Imitator	*2½*	*½*	*0*	*0*

The outcomes of this game again suggest multiple equilibria (Figure 3). When mapped against time, several stable asymptotic solutions (and several unstable solutions) emerge, ranging between 0 and 1.

The relevance of these models becomes apparent when we consider how societies organize themselves over time, how institutional design contributes to determining these evolutionary processes, and how the outcomes of these processes may or may not be optimal.

Figure 3: Innovator/Adaptionist/Complementor/Imitator Game



First, the models suggest that institutional design is important. Given a set of *n* agents in a particular game, any change in the payoff structures may change the outcomes of the game. So, for instance, a sufficiently enforced law against piracy might reduce the payoffs to Imitators regardless of whom they interact with. Likewise, a sufficiently enforced intellectual property rights regime might increase the payoffs to Innovators with or without consequence to Adaptionists' payoffs, depending on the nature of the regime. Institutional design, whether the result of spontaneous emergence or of choices made by system actors, necessarily influences the nature and character of the system.

Second, the models suggest the importance of change over time. Institutional design may spontaneously or consciously change as the system evolves in a given direction. For instance, an innovation system operating in a society that prioritizes the welfare of Adaptionists such as small farmers may, in the early years of agricultural modernization, choose to limit the payoffs of being a private sector Innovator. In the long run, however, society may choose to replace such policies with interventions that favor the private Innovator by, say, reducing the crowding-out effects of public sector investment in agricultural research, or reallocating public research to a basic/strategic function only. Changes in institutional design over the long term necessarily influence the nature and character of the system.

Third, the models suggest that optimality is not a necessary outcome of evolutionary processes. It should be obvious that optimality does not necessarily obtain from these models; rather, stability obtains, and only under certain circumstances. Indeed, it is difficult to identify conditions for optimality or paths thereto in a dynamic innovation system that evolves from market inefficiencies, endogeneity, serendipity, and nonmarket institutions, or from a system that generates multiple equilibria and Pareto-inferior outcomes. But where policies can be designed to affect the evolutionary process of innovation, then the trajectory of a system can potentially be guided toward greater innovative output and more favorable distributions of innovative rents and social welfare.

Thus, the evolutionary models described above suggest that public policy can play a role in transforming an innovation system by changing the rules of the game and the sequence in which the rules are applied. In effect, this implies that there is a role for public policy beyond the correction of imperfect markets as identified by neoclassical economics (e.g., market power) and beyond the correction of imperfect institutions as identified by new institutionalist economics (e.g., coordination failures). Rather, the role of public policy should be to (a) enable an innovation system to remain flexible and diverse enough to avoid becoming locked into a single trajectory, (b) create incentives for innovative activity, and (c) create institutions that respond to and learn from the innovative process.

Finally, note that this model illustrates only one possible set of agents, interactions, and outcomes in an innovation system. Other models can be developed to describe the relationship between, say, a smallholder farmer, a public extension worker, and an agronomist, or between capital-intensive farmers, smallholder farmers, and providers of a technologically advanced (or locally appropriate) technology. This flexibility is what makes game theoretic and population game models so useful in analyzing complex systems. Still, the point here is not to describe all possible agents, interactions, and outcomes but to provide a model that helps illustrate the complexities encountered when heterogeneous actors behave strategically, and how their behavior generates certain evolutionary outcomes within a broad system.

Discussion

The models described above lead directly to several empirical research questions relevant to developing-country agricultural that can be addressed within the innovation systems framework. These questions are as follows:

- How do we accurately describe and model research and innovative activity as part of a system, society, or economy that changes over time?

- How does policy affect the processes that determine the range and scope of innovations that are generated and disseminated within a system, society, or economy?
- How does policy affect the processes that determine the distribution of the social and economic gains from innovation?

With these questions in mind, this section reviews several areas in which the application of an innovation systems approach can contribute to the improvement of pro-poor agricultural research and innovation in developing countries, and in which the approach and its applications are still under development. How applied innovation systems research proceeds in light of these recommendations may determine its relevance to improving the impact of agricultural innovation on poverty reduction, food security, agricultural development, and economy-wide growth in developing countries.

Defining the Role of Institutions

The most apparent value of the innovation systems framework lies in its ability to widen otherwise narrow or conventional analytical perspectives on developing-country agricultural research and innovation. The framework offers a more comprehensive analytical perspective than the NARS or AKIS perspectives by emphasizing the study of interactions and processes among diverse agents and institutions involved in the innovation process.

But beyond this contribution, there is limited evidence to suggest that the full value of the framework is being applied to understanding how innovation occurs and designing mechanisms that strengthen agricultural innovation systems in developing countries. Some of the emerging literature on agricultural innovation systems remains tied to conventional interest in the structure and reform of brick-and-mortar public sector "institutions" rather than the "rules of the games" that describe the wider characteristics of an innovation system (see, for example, Chema, Gilbert, and Roseboom, 2003). And several agricultural research initiatives, while using the language of the innovation systems approach to suggest a new analytical perspective, seem closely wedded to the conventional priority of strengthening national, public sector partners without fully recognizing the complexity of the processes and systems within which these partners operate (see, for example, FARA, 2004, and Roseboom, 2004). In short, early applications to developing-country agriculture suggest a far narrower—and, arguably, less informative— approach that revolves around the trials and tribulations of a single, typically public sector, agent. This overlooks the analytical strength of the innovation systems framework and its unique approach to understanding complex and diverse agents, institutions, and interactions.

Admittedly, this narrow approach reflects certain realities in developing-country agriculture. Agricultural research and innovation in many developing countries are focused on attaining food security and alleviating poverty by enhancing crop yields for farmers and improving food availability for consumers with limited market access or purchasing power. This strategy has traditionally required that research outputs be generated as nonexcludable, nonrival (public) goods, requiring, in turn, public sector investment in research and innovation. This is most acute in Sub-Saharan Africa, where more than 97 percent of agricultural research is undertaken by the public sector (Beintema and Stads, 2004). But it is no less relevant in Asia and Latin America.

However, these narrow approaches overlook the importance of understanding the wider system and process of social and technological change in agriculture, the institutional factors that underlie these processes, and the potential impacts on research and innovation. More importantly, these narrow approaches do little to change the nature of how innovation occurs in developing-country agriculture, leaving many puzzles unanswered.

Thus, more study of the dynamics of innovation is needed. This includes the study of nonstate actors in relation to, separate from, or even in spite of public sector research organizations. Several studies (e.g., Hall et al., 2002, 2004) attempt to do this, representing an important directional indicator for the literature. But more study is required on heterogeneity among nonstate actors, changes in the institutional contexts in which heterogeneous actors operate, and alternative forms of interaction among heterogeneous actors.

Tools and Methods of Analysis

In its application to the study of innovation policy in OECD countries, the innovation systems approach relies on a diversity of rigorous qualitative and quantitative methods. The choice of method has been driven by two separate strains in the literature (Balzat and Hanusch, 2004). The first strain derives from academic efforts to improve our understanding of how innovation occurs, and relies on tools such as country case studies and descriptive models of national innovation systems, which, until recently, have lacked a formal method of analysis. The second strain derives from more policy-driven efforts to improve the performance of national innovation systems, and relies on tools for conducting cross-country comparisons such as innovation benchmarking and ranking and comparative case studies of best practices.

The literature is increasingly characterized by the use of a wide variety of systematic, replicable, and consistent tools of analysis, including in-depth social and economic histories; policy benchmarking, cross-country comparisons, and best practices; statistical and econometric analysis; systems and network analysis; and empirical applications of game theory, to name but a few (Balzat and Hanusch, 2004). This methodological diversity and rigor bring credibility and strength to the study of innovation systems.

However, in its current application to developing-country agriculture, the innovation systems approach is making limited use of these powerful tools and methods. Currently, the favored methodology in the study of agricultural research in developing countries is the descriptive case study, often drawn from an action research or stakeholder analysis exercise (Hall et al., 2004). Several recent studies have become more diagnostic in their approach by identifying institutional constraints and recommending alternative policies, incentive structures, or organizational reforms that might remove such constraints (Kangasniemi, 2002; Hall et al., 2002; Hall et al., 2004). But more often than not, studies are simply *ex post* descriptions of the dynamics and complexities of some technological or institutional innovation. And there the analysis ends.

This is not to say that action research lacks rigor; rather, action research has been a fundamental tool in identifying agricultural innovation systems in developing countries and establishing "proof of concept" for further study. However, reliance on action research should not preclude the use of other equally rigorous qualitative and quantitative methods. In fact, greater diversity in the choice of methods can only strengthen the literature by improving the robustness of hypotheses testing based on the innovation systems framework.

Consider several possible methodological approaches with which to strengthen the study of innovation systems in developing-country agriculture. One might be to analyze the costs and benefits of knowledge production or dissemination given the complexity of interactions among diverse agents. Such an approach could include standard measurements of costs and benefits combined with measures of transaction and risk management costs that are so fundamental to many different types of nonmarket interactions. An alternative approach might be to employ well-developed methodologies used in the study of social learning processes among agrarian agents (Foster and Rosenzweig, 1995; Conley and Udry, 2001).

Yet another approach might be to consider the dynamic effects of market structure on the innovation process using empirical applications of cooperative game theory and other tools of industrial economics. This is illustrated by Naseem and Oehmke (2004), who model R&D races under various oligopoly scenarios in which public and private researchers are both conducting work on advanced genomics research; they suggest that under a certain set of market conditions, public organizations can play a role in increasing the level of genomics research despite the nature of the R&D race.

Another useful method, already employed by the OECD in its studies of innovation systems in industrialized countries, is benchmarking, or best practice (OECD, 2002, 2001). Through comparative studies of innovation systems, this method allows researchers and policymakers to compare the dynamics of innovation—the policies, institutions, organizations, and processes that influence innovation outcomes—in one country or region against another. This approach requires the identification of appropriate indicators of innovation, including not only R&D investment statistics but also indicators of absorptive capacity among firms; the quality and quantity of investments in human capital; labor, input, and commodity market conditions; infrastructure; and so on.

Still another useful tool, addressed briefly in Section 4 above, is the empirical application of noncooperative game theoretic models to break down interactions into key decision points and payoffs. Methodologies in this vein include descriptive modeling of the relations and networks through which information moves between and among agents.

This is a particularly powerful set of tools in analyzing knowledge-intensive sectors such as agricultural research. For example, Binenbaum, Pardey, and Wright (2001) dissect the relations between organizations, the incentives that motivate their behavior, and the problems associated with those incentives. By reconstructing the relations and incentives under alternative scenarios, the analytical output, typically embedded in game theory, develops an enhanced perspective on the process by which information flows between organizations. Key elements include analysis of players and their objectives, incentives, and relations; the structure and flow of information and the mechanisms that make information flows possible; the choice variables and sequence of moves among players; and the relation and incentive problems that impede players' moves and the flow of information. Similarly, De Bruijn and Van der Voort (2002) study interactions such as public-private partnerships by identifying the dilemmas and tensions that characterize the interaction with the use of a combined product and process analysis (i.e., input-throughput-output) approach.

The novelty and context-specificity of a given innovation, however, often necessitate less intricate methods that rely on descriptive or comparative analysis of agents and their mechanisms of interaction. However, if the action research approach falls short in this context, another method developed by Elliott et al. (1985) and Elliott (1990) might prove useful. This approach, referred to as *agricultural technology management system (ATMS) analysis*, attempts to analyze the interrelationships both within and among organizations, and between organizations and their external environments to improve organizational design and managerial functions. The approach emphasizes separate analyses for systems, organizations, and technologies, and offers a variety of analytical tools such as responsibility charting, events analysis, priority setting, and so on.

The ATMS approach alludes to the possible use of other, more conventional tools common to the study of business management and organizational behavior—tools that could improve our understanding of the inner workings of public research organizations, private research firms, and nongovernmental organizations. These might include such exercises as analysis of innovation processes within value chains (Kaplinsky and Morris, 2000; Humphrey and Schmitz, 2001). The value chain approach examines how producers, buyers, and sellers separated by time and space progressively add and accumulate value as commodities are transformed and passed from one member of the chain to the next, and how product and process innovations can improve the efficiency of the value chain.

In sum, it would seem that the innovation systems framework, when applied to developing-country agricultural research, is making limited use of the diverse analytical tools available in the existing literature on innovation systems and in other areas of empirical inquiry. More effort is required to identify measures and accumulate data on national and sectoral innovation systems and develop taxonomies with which to classify agents, institutions, and systems. With more information of a better quality, innovation systems researchers will be able to more accurately model the calculus of agents' behavior with respect to each other's strategic behavior and in the context of social and economic institutions; make meaningful comparisons over both time and space; and suggest alternative policy options to strengthen innovation systems.[7] Even recognizing the data limitations in developing countries, these approaches are not infeasible.

[7] By way of example, the Consultative Group on International Agricultural Research (CGIAR) could consider updating its Agricultural Science and Technology Indicators (ASTI) initiative to reflect the more comprehensive approach taken by the OECD (1999).

Relevance to Policy Analysis

Methodological issues aside, the value of the innovation systems approach is its use in informing policymakers of options that may enhance the potential for innovation and improve the distribution of gains from innovation. Recommendations in this vein emanate from studies such as Kangasniemi (2002) on policies to strengthen the research role of agricultural producer associations in East and southern Africa; Hall et al. (2002) on enhancing opportunities for public-private partnerships in Indian agriculture; and in several studies presented in Hall et al. (2004) on partnerships, institutions, and learning in South Asia and Sub-Saharan Africa.

Yet beyond these (and several other) examples, the link between empirical analysis and policy recommendation remains either nascent or weak in the application of the innovation systems framework to developing-country agriculture. With so many case studies conducted and so many lessons learned, researchers should be well positioned to advise governments on policy options and incentive structures that generate greater levels of innovation and improve the distribution of gains therefrom.

It may be argued that advising governments with research-based policy recommendations is an old-fashioned, top-down approach to promoting change, and that institutional learning through action research and capacity-strengthening efforts is more effective. Indeed, there is a growing consensus behind the need for strategies that combine policy research with effective capacity-strengthening and communication approaches (Young, 2005; Court and Maxwell, 2005; Von Grebmer, 2005; Court and Young, 2004; Pannell, 2004). What remains to be seen, however, is whether institutional learning approaches offer better and more cost-effective access to the leverage points needed to change institutional design and public policy than, say, conventional policy recommendations and advising. At present, the esoteric nature of the innovation systems literature as applied to developing-country agriculture provides insufficient evidence to conclude that this is the case.

The general absence of policy analysis in the emerging literature may result from the complexity of a "systems" approach and the weakness of its associated methodologies, a point not lost on Clark (2002). Case studies and action research may help illustrate complex relationships and assemble seemingly unrelated bits of knowledge, but they are insufficient tools with which to persuade policymakers and effect policy change. The absence of policy analysis may also result from the depth, breadth, and complexity of innovation policy—a topic covering policies in industry, agriculture, trade, finance and investment, education, science and technology, labor, and so on. But to effect real change, analysis of innovation policy should extend from case studies to more comprehensive analyses of national and sectoral policies at a level where lessons learned can be used to craft and coordinate policy options, or to make constructive cross-country benchmarks and recommendations for best practice. By combining well-grounded empirical analysis with a solid understanding of the institutional context in which innovation occurs, the innovation systems approach can be a powerful tool in the design of public policy and incentive structuring.

This concept ties closely to Omamo (2003), who argues that policy analysts must pay closer attention to processes of institutional innovation and their historical, socioeconomic contexts, and rely less on formula-based prescriptions for agriculture in Africa. Here, the innovation systems framework offers the right focus on institutional innovation, institutional context, and historic path-dependency, but needs to extend itself into the realm of policy analysis by asking the right questions: *how* alternative policy options can be designed, implemented, and operationalized, rather than *why* innovation systems look the way they do in developing countries.

Relevance to Poverty Reduction

Finally, the innovation systems framework provides a new perspective on innovation processes that are fundamental to reducing poverty and improving food security. This is highly relevant when the framework is extended to the study of agriculture in developing countries, where 75 percent of the world's poor are resident (IFAD, 2001). Yet few studies in the emerging literature on innovation systems in developing-country agriculture ask the fundamental economic question: whether a given innovation is welfare increasing. This means asking whether an innovation increases efficiency in the production or utilization of knowledge directly relevant to those goods and services used by the poor in consumption or production, or whether an innovation improves the distribution of social surplus in a manner beneficial to the poor. Few studies make that leap from descriptive *ex post* analysis of an innovation system to an *ex ante* analysis of how an innovation system promotes institutional and technological changes that are explicitly pro-poor. Although some authors (e.g., Kangasniemi, 2002) reference smallholder African farmers as a key target group for innovation-relevant policy improvement, there are few other examples of distributional or poverty analysis in the innovation systems framework. Ultimately, by putting innovation (rather than poverty) at the center of its study of developing-country agriculture, the innovation systems framework is limiting its relevance and value to developing-country agriculture.

More work needs to be done within the innovation systems framework on the relationship between innovation—both technological and institutional—and poverty. This implies studying both the economic growth prospects associated with innovation and the distributional consequences of innovation. The former opens up a whole new field of macroeconomic inquiry that combines innovation systems perspectives with endogenous growth theory (e.g., Romer, 1990; Barro and Sala-i-Martin, 1995). This type of marriage enhances the study of economic growth by providing new perspectives and indicators that better capture and measure innovative capacities (Balzat and Hanusch, 2004).

The latter offers possibilities for analysis of key themes in the study of technological change in agriculture. This includes analysis of how innovations affect wages for landless laborers, incomes for smallholders, or bargaining power for vulnerable social groups, implying more analysis of distributional and political economy issues—for example, the distribution of income, knowledge, and power and their relationships to innovation processes. This also includes analysis and valuation of tacit, nontraditional, and nonindustrial knowledge sources often held by those with the least ability to realize the benefits of innovation—small-scale farmers, food-insecure households, landless agricultural laborers, women and children, and other marginalized or vulnerable groups. And finally, this could include a greater focus on *ex ante* analysis of how innovation policy affects poverty reduction by making use of the tools and methods suggested above and by focusing less on *ex post* descriptives of innovation systems.

5. Conclusions

The organizing principles of the innovation systems approach—to study interactions and institutions that affect heterogeneous agents' strategic efforts to innovate, adapt, and complement—is an important break from the neoclassical principles of optimizing agents and equilibrium outcomes. In agriculture, these perspectives are critical to shifting socioeconomic research beyond technological change "induced" by the relative prices of land, labor, or other production factors in agriculture, and beyond the concept of linear technology transfers—from industrialized to developing countries, from advanced and international research centers to national systems—as an engine of change.

The innovation systems perspective argues against the perception that technological change drives social and economic development, instead suggesting that the institutional context in which technological change occurs drives development. With a better understanding of the institutional context, we are better able to understand the impacts of technological change on vulnerable social groups in rural society. The innovation systems perspective is useful in that it widens otherwise narrow horizons in the agricultural research community. The framework can be used to fill knowledge gaps and frame socioeconomic research within a wider context of diverse actors, knowledge sources, institutions, and interactions.

But the literature requires further development and application to be of relevance in the context of developing-country agriculture. Much of the emerging literature in this area demonstrates certain limiting qualities: a lack of perspective beyond the conventional role of the public research organization; few methodologies beyond ungeneralizable, context-specific descriptive analysis; limited relevance to policy analysis and policymakers; and limited relevance to poverty reduction and food security.

New applications of the innovation systems framework to developing-country agriculture should include more analysis of agents and agent behavior, the institutions that condition their behavior, and the diverse interactions that characterize their behavior. Furthermore, such applications should include more in-depth study of the policy options that may affect the innovative process and steer it toward more welfare-improving outcomes. With this approach in mind, and undertaken with a set of diverse tools at hand, the innovation systems framework offers great potential as a new mode of inquiry in the study of developing-country agriculture.

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