

**Developing the Art and Science of Innovation Systems Inquiry:  
Alternative Tools and Methods and  
Applications to Sub-Saharan African Agriculture**

by

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## **Abstract**

Agricultural education, research, and extension can contribute substantially to enhancing agricultural production and reducing rural poverty in the many parts of the developing world. However, evidence suggests that their contributions are falling short in sub-Saharan Africa. The entry of new actors, technologies, and market forces, when combined with new economic and demographic pressures, suggests the need for more innovative and less linear approaches. This paper explores methodologies that can help improve the study of agricultural innovation in the region. The paper examines methods that address three specific issues: (a) how agents interact in the production, exchange, and use of knowledge and information within a system; (b) how agents respond individually and collectively to technological, institutional, or organizational opportunities and constraints; and (c) how policy changes can enhance the welfare effects of these interactions and responses. Methods for further exploration include social network analysis, innovation histories, cross-country comparisons, and game theoretic modeling.

## 1 Introduction

Agricultural education, research, and extension can contribute substantially to enhancing agricultural production and reducing rural poverty in the many parts of the developing world. However, evidence suggests that their contributions are falling short in responding to new opportunities and constraints in regions such as sub-Saharan Africa, where agriculture continues as the region's primary source of livelihood. The entry of new actors, technologies, and market forces, when combined with new economic and demographic pressures, suggests the need for more innovative and less linear approaches.

Recent attention to these issues have focused on the wider "innovation system," an increasingly popular concept in the study of how societies generate, exchange, and use knowledge. An innovation systems framework emphasizes the study of complex adaptive systems where the actions and interactions of diverse agents are conditioned by numerous formal and informal socioeconomic institutions. The framework captures not only the influences of market forces, but also the influences of organizational learning and behavioral change, non-market institutions, public policy, and socioeconomic transformations.

Most importantly, the innovation systems framework shifts the analytical emphasis from a conventional and linear model of knowledge transfers to a more complex process-based systems approach. This shift is appropriate for the study of agriculture in Sub-Saharan Africa given that the sector's growth and development is becoming increasingly influenced by complex interactions among public, private, and civil society actors, while knowledge flows within the system are being conditioned by a variety of rapidly changing institutions.

But early applications of the framework suggest opportunities for more intensive and extensive analysis. There is ample scope for empirical studies to employ more diverse methodologies, both qualitative and quantitative, than are being used at present. Further, there is room to improve the relevance of empirical studies to the analysis of poverty reduction and economic growth.

This paper explores methodologies that can help improve the study of agricultural innovation in Sub-Saharan Africa. The paper examines methods that address three specific issues in this context: (a) how agents interact in the production, exchange, and use of knowledge and information within a system; (b) how agents respond individually and collectively to technological, institutional, or organizational opportunities and constraints; and (c) how policy changes can enhance the welfare effects of these interactions and responses.

The paper proceeds as follows. Section two sets forth a conceptual framework based on complex systems and innovation in complex systems. Section 3 discusses the methodological limitations of conventional approaches to the study of innovation systems. Section 4 presents some the key methodological issues facing alternative methods, followed by a discussion of these alternatives in Section 5. Conclusions are given in Section 6.

## 2 Conceptual Background

### A. Complex Systems

The basis for development is the ability of individuals, organizations, and societies to improve on what they are currently doing, i.e., to improve their individual and collective capabilities. But such improvements are necessarily contingent on the environment within which innovation occurs. Individuals and their environments form complex systems characterized by large number of actors, diverse interactions and relationships, and constantly-changing influences emerging from technological, market, policy, cultural, and other social and economic factors.

Recognition of development as a complex process can have major consequences for the design and implementation of public policy. However, such recognition is still relatively uncommon. Public policies still draw on conventional analyses that are based on modernist metaphors of hydraulics, machinery, and factory production. This mechanistic vision continues to exert a profound influence on the design of organizations, institutions and policies: social scientists and policymakers still emphasize control and predictability, and still design interventions that are built from the top down and expected to be implemented through passive, subordinated structures (Olson and Eoyang 2001).

Complexity theories, on the other hand, emphasize the importance of self-organization, which results from the diversity of agents and decentralized nature of complex systems. Even though some agents have more influence than others, no agent or group of agents can totally control the system. Thus, policies in a complex system do not seek to “manage” the system but to operate on the probability of events, to increase the odds of desired outcomes, and to reduce the chances of undesired results (Axelrod and Cohen 1999).

In this paper we define a complex system as one whose properties cannot be analyzed by studying its components separately (Gallacher and Appenzeller 1999). While there are several types of complex systems, the most relevant for the study of innovation processes are termed “Complex Adaptive Systems” (CAS), or systems formed by many agents of different types, where each defines his/her strategy, reacts to the actions of other agents and to changes in the environment, and tries to modify the environment in ways that fit his or her goals (Kauffman 2000).

In the context of developing-country agriculture, CAS can be used to describe a system of commercial farms, smallholder farms, public extension agents, public researchers, and market agents such as traders and brokers; public policies on science, technology, agriculture production and agricultural marketing; and the ongoing (though rarely linear) transformation of smallholder agriculture from subsistence to commercial production modalities.

From the actions and interactions within this CAS, behavioral patterns emerge that are specific to groups of agents and to the system as a whole, but do not exist at the level of individual agents. For example, a piece of wood is formed by identical carbon atoms. The wood, however, is characterized by strength, color and smell, features that individual atoms do not have. This example shows that the outcomes of CAS differ according to the scale at which the study is conducted. The example also demonstrates the principle of self-organization—the independent, spontaneous, or unintended emergence of a complex

system—and how complexity renders conventional, mechanistic modes of analysis quite useless.

CAS evolve through the combination of initial conditions, multiple interactions, trends, and random variations in agents and their interactions. The strength of the trends and of the random effects changes along an evolutionary path. When the trends are strong, the CAS is more or less predictable; as the system evolves and new actors and interactions emerge, the CAS becomes less stable. Eventually, the random component may become more important than the trends, and at a certain bifurcation point, the system may become absolutely random and unpredictable (Nicolis and Prigogine 1998).

The systems do not tend toward chaos, but to a situation that is inherently unstable and unpredictable. At any given moment, random variations occur with varying consequences and varying degrees of predictability. When the trends dominate, the probability that a random variation results in a *minor* event is high; when variations occur close to unstable configurations, the probability of *catastrophic* events is high.<sup>1</sup>

Even though it is possible to study the probability distribution of these random variations, it is not possible to know in advance whether the next event will have minor consequences or if it will trigger large changes (Kauffman 1995). The study of past events enables a better estimation of the probability of future events, but because such estimations are contingent on the continuation of past processes into the future, the uncertainty cannot be completely eliminated. This feature of CAS has major implications for public policies aimed at promoting growth and development. These policies seek to actively change these processes; in other words, human interventions reduce the potential for predicting the outcome of the implemented policies.

One of the most important evolutionary forces in complex systems is the interaction between variation and selection. New actors and strategies constantly emerge, but not all of them are adapted to the environment; selection enables “survival of the fittest.”

Recent studies of biological systems yielded a greater understanding of this process. First, contrary to what was asserted by the traditional theories of evolution, phenotypes do not evolve gradually toward an optimum. Second, changes in biological efficiency are discrete, interrupted by long periods of relative stability. And third, genetic evolution, measured in terms of DNA sequences, does not stop in the periods of stability of phenotypes but continues at least at the same rate as in the periods of adaptive innovations.

Instead, evolutionary changes occur without an external trigger, indicating the existence of neutral evolution, i.e., changes in genotypes that do not have a phenotypical expression (Crutchfield and Schuster 2003). This type of punctuated dynamics has also been observed in non-biological evolutionary processes.

These examples demonstrate that complex processes are, in fact, collections of sub-processes that evolve at different speeds but influence each other. In the case of CAS, there are essentially two important interacting dynamics: a very fast process at the genotype level and a slow one at the phenotype level.

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<sup>1</sup> In the specialized literature, catastrophic refers to an event that changes the “essence” of the process and does not have the negative connotation the word has in common language.

For example, consider the manipulation of variation and selection—one of the most powerful instruments to operate on complex systems. In natural systems, variations are random and the selection criterion is reproductive fitness. Human interventions can operate on both mechanisms, as exemplified by plant breeding. A plant breeder knows the lines he/she uses in his/her crosses and chooses those he/she expects will pass specific traits to its offspring (e.g. resistance to a disease). In the first crossing cycle, the breeder makes thousands of crosses, most of which do not occur naturally.<sup>2</sup> In other words, the breeder has increased the variation with crosses he/she expects have a large probability of yielding the desired results. In artificial selection the breeder replaces the criterion of disease resistance for the natural criterion of reproductive fitness. Similar manipulations have been successfully used to develop complex computer programs, to obtain new chemical compounds and medicines, and to manage large ecosystems.

This example illustrates an important difference between operating from the traditional mechanistic perspective and a complexity framework. In the former, “solutions” to “problems” are designed in a detailed research and development process. In the latter, the solutions are obtained by a search process without designing them intentionally. This difference can be exemplified with the development of a chemical molecule (B) that should bind to another molecule (A). In the traditional approach, chemists prepare a detailed model of molecule A, design a molecule B that can potentially bind to A, and then develop a process to synthesize it. In the complexity approach, chemists attach millions of A molecules to a surface and run a “chemical soup” over it with hundreds of millions of potential B molecules. Then, they clean the surface and recoup those molecules that attached themselves to the A molecules. Each of the attached molecules is a potential candidate for the B molecule (Crutchfield and Schuster 2003).<sup>3</sup>

The relative effectiveness of both methods depends on the complexity and stability of the processes that policymakers want to influence. If little is known about the process, if it is complex or changes often, rational design is less efficient because it limits the exploration of potential solutions, and gambles that the designed solution is the most effective. In such cases, the effectiveness of rational design depends more on chance than educated search procedures based on the manipulation of variety and selection. It has been shown that search methods converge to the optimum at least as fast as rational design (Crutchfield and Schuster 2003). In social systems it is impossible to try millions of solutions; thus, different search methods should be used (see below).

“Failures” are common in complex systems; for example, it is estimated that in the 20<sup>th</sup> century less than 10 percent of firms have been able to grow consistently for long periods (Christensen and Raynor 2003). The reason for this failure is that only agents with strong abilities to adapt to changing conditions can survive in complex processes that are difficult to understand and predict. Additionally, few organizations have the ability to change structures that have worked in the past and that are still operating successfully at the time when new structures need to be developed (Bailey and Ford 2003; Christensen and Raynor 2003). Even more, as appropriate strategies to operate in complex environments are very different from

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<sup>2</sup> Natural crosses usually happen between a few neighboring plants, resulting in relatively small genetic variations between successive generations.

<sup>3</sup> This approach, known as molecular breeding, is used to develop chemical compounds and, involuntarily, was used by Monsanto to find the gene that made plants resistant to glyphosate (Charles 2001).

those used in “simple” processes, few organizations have the knowledge and human resources to develop alternative strategies.

In simple processes, it is possible to develop an adequate understanding of the main trends; thus, the best strategy is to make a careful plan and implement operations that strictly follow the plan. In complex processes, on the other hand, decisions must be made with limited understanding of the main dynamics. For this reason, the strategic objective should not be to plan the implementation but to plan the learning. Decision makers must identify what crucial information is missing and in which order it will be required. Plans should reflect these priorities, so that the information is available when needed. These methods are known as discovery-driven planning (Christensen and Raynor 2003).

Discovery-driven planning is based on the recognition that the processes are little known and includes four steps: (a) decision makers use partial information to build mental models of the processes; (b) they challenge the assumptions used to build the model; (c) they use pilot projects to discover the most important dynamics and to test the initial assumptions; and (d) they keep an appropriate reserve of financial and human resources to have flexibility to change course if the initial assumptions are proved wrong.

Strategic planning and planning by objectives in general fail when applied to complex systems because they do not have the flexibility to identify emergent opportunities. When results deviate from the objectives, these planning methods recommend investing additional resources to close the gap between what was planned and what is being achieved. From a complexity theory perspective, on the other hand, these deviations are seen as unanticipated potential opportunities that should be explored. In fact, often the largest benefits come from these unexpected opportunities (Christensen 2003). Only when decision makers have the mental flexibility to identify these opportunities and enough reserves, can they take advantage of unexpected opportunities.<sup>4</sup>

## **B. Innovation in a complex system**

Innovation has been defined in different ways. In this paper we define an *innovation as anything new successfully introduced into an economic or social process*. In other words, an innovation is not just trying something new but successfully integrating a new idea or product into a process that includes technical, economic, and social components.<sup>5</sup>

This definition stresses three important features. First, innovation is the creative use of different types of knowledge in response to social or economic needs and opportunities (OECD 1999). Second, a trial only becomes an innovation when it is adopted as part of a process; many agents try new things, but few of these trials yield practices or products that improve what is already in use. Third, innovations are accepted as such in specific social and economic environments (Bailey and Ford 2003). A sighting pole at the end of a plot is an innovation for a small Ghanaian farmer because it helps him/her to plant in straight lines (Ekboir, Boa and Dankyi 2002), but a new method for sequencing DNA is not, since the farmer has no use for these high-tech methods.

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<sup>4</sup> Serendipity does not happen to anybody; only to those who are looking for something. They just do not find what they were looking for, but something else (Georgsdottir, Lubart, and Getz 2003).

<sup>5</sup> Schumpeter (1950) introduced this distinction when he distinguished invention (a new idea) from innovation (implementation of the idea).

In the terminology of complexity theory, innovation results not just from variation (trying something new), but also from selection (finding things better than what is currently used) and incorporation into long, complex processes. Moreover, innovation processes are essentially complex because if they could be planned in advance, they would not be innovative (Nickles 2003).

Innovations can have an important socioeconomic impact only when they are part of sustained processes involving many actors with different capabilities. The reason is that if an innovation improves substantively, say, production, it must be accompanied by new managerial and marketing innovations to handle and sell the extra output.

Today, it is recognized that individual actors (including private firms) usually do not have all the human, social, and financial resources they need to innovate at a rate that enables them to survive in competitive markets. For this reason, they integrate into innovation networks with other actors who can contribute resources and expertise they lack (Rycoft and Kash 1999; Christensen and Raynor 2003). In other words, the key to successful innovation networks is to gather sufficient variation in skills. Many development programs induce the creation of farmers' groups. However, these groups may not have enough variety to develop successful innovative capabilities. To raise the probability of success, they have to partner with other types of agents (e.g., market traders or extension agents).

Integration into these networks, however, is difficult because of known problems of implementing collective action: the difficulties of agreeing on and implementing rules, the need to create trust, and the problems of monitoring opportunistic behaviors. The network dynamics depend on evolving relationships among internal and external agents, technical change, market developments, and the formal and informal rules that condition interactions among agents.

The networks' structure and dynamics depend on the innovations' complexity and maturity. In the case of simple or mature innovations, networks are loose. Because the economic and technical features of the innovations are relatively well known, members can relate to each other through formal contracts or markets. These cases have usually been the model for traditional economic studies, and are the basis of many agricultural development programs. For new or complex innovations, actors have to interact often and informally to overcome unexpected problems and the technical and market uncertainty derived from the innovation (Christensen and Raynor 2003; Rycoft and Kash, 1999).

The effectiveness of innovation networks depends on their capacity to facilitate exchanges of information and resources. In the terminology of network analysis, this capacity is known as the network's navigability, and it depends on the existence of "central" actors (i.e., well connected actors) interacting among themselves (Buchanan 2002), and on the environment (i.e., laws or markets) in which the networks operate.

One of the main hurdles that diminish small farmers' innovative capabilities is their inability to integrate into navigable networks that enable them to access technical and commercial information, markets, and financing. These groups do not have enough human and social resources to develop successful searching capabilities.

In the long term, networks' abilities to innovate depend on their ability to search for and use existing information and, and when it is not available, to generate it; in other words, on the networks' ability to develop organizational capabilities (Dosi, Nelson, and Winter 2000). In the specialized literature, it is recognized that organizational capabilities lay in individuals, technology, and the organization's structure, including routines and methods to coordinate resources (Argote and Darr 2000). From this perspective, networks and organizations are social communities that use their relational structures and shared codification schemes to build mechanisms to transfer and communicate new abilities (Zander and Kogut 1995) and to condition individual innovative capabilities (Bailey and Ford 2003).

Collective capabilities emerge from the interaction of resources (individuals and fixed capital), processes (how things are done in the network or organization) and values (including institutional cultures and long-term objectives). In new organizations, most capabilities reside in the resources, especially its people. With time, capabilities are transferred to processes and values (Christensen and Raynor 2003).

Capabilities are unique to each network or organization—they are developed through investments and idiosyncratic processes – and other organizations cannot buy them or imitate them easily. This is the main reason why some organizations succeed where others fail. Finally, capabilities are contextual; what can be an ability in a specific context can be a disability in another situation (Appleyard, Hatch and Mowery 2000; Christensen 2003).

### **3 Methodological limitations of the conventional approach**

The innovation systems literature, with its basis on complexity theories, is a major epistemological departure from the traditional, neoclassical studies of technical change. Many authors, however, have considered innovation as just the last step in the continuum from research to technological change (Byerlee and Alex 1998; Sunding and Zilberman 2001).

Several reasons prevent the use of microeconomic models for the analysis of innovation processes. Microeconomics models posit the existence of a stable function that links inputs and outputs. As the modeling of complex evolutionary systems has shown, however, these systems cannot be represented by a single function whose gradient determines the evolutionary process (Crutchfield and Schuster 2003). Even if such function could be specified, it has been shown that evolutionary processes do not move toward an optimum, i.e., the method to derive analytical solutions does not represent the true data generation process. The impossibility of representing the process in a simple way led academics to develop evolutionary models of decision making (e.g., Nelson and Winter 1982).

A further issue is the stability of the objective function. Innovation is essentially learning; in other words, the ability to combine inputs in different, more efficient ways and/or to introduce new inputs. If a production function could be specified, its parameters should themselves be dynamic nonlinear functions of an agent's innovative capabilities; in other words, as actors strengthen their innovative capabilities, the function changes in non-trivial ways.

Additionally, a basic assumption of neoclassical models is that agents only interact with other agents through markets. Market failures arise when this assumption does not apply. Studies on innovation, however, have shown that non-market interactions are a necessary condition

for successful innovation. Accounting for these interactions is not trivial. For example, using statistical mechanics, Ioannides (1997) showed that the system's path depends crucially on how the interactions are modeled.

Two additional problems hamper estimation of empirical models. First, econometric methods can be used only if a common function for all observations exists. The dependence of the parameters on the innovative capabilities, however, guarantees that such a common function does not exist. A function for the innovative capabilities cannot exist because innovations are contextual; in other words, what is an ability in a particular context can be a disability in another situation.

Second, it has proved impossible to find measures of innovation that have universal application. The definition we introduced above includes new techniques as well as institutional changes; often, the innovations are just attitudinal changes. Many studies have used scientific publications, patents, and other forms of intellectual property rights as an indicator of innovation activities. These measures, however, apply only to a few science-intensive sectors. For countries and sectors that are not at the technological frontier, it is more important to absorb existing information than to create knowledge new to the world (Metcalf 2000).

#### **4 Methodological challenges for innovation systems studies**

Systems-based approaches are not new in the agricultural development literature. The study of technological change in agriculture has always been concerned with systems, as illustrated in applications of the national agricultural research system (NARS) and the agricultural knowledge and information system (AKIS) approaches. Thus, the agricultural innovation system (AIS) approach does not necessarily supplant prior approaches, but looks at them from a different perspective.

The NARS approach, for example, emphasizes the role of public sector research organizations in generating and disseminating new technical information. The approach recognizes that the outcomes of agricultural research are often a public good (non-excludable and non-rival) with social benefits that exceed private benefits, resulting in chronic undersupply by market forces and thus requiring public intervention. A major shortcoming of this approach is that the main restriction to the use of technical information is not its supply but the limited ability of innovative agents to absorb it. Even though technical information may be free, innovating agents have to invest to develop the ability to use the information (Nonaka and Takeuchi, 1995). Everybody can read a manual on how to repair a car, but only a trained mechanic can do it well and fast. Other people have to invest time and effort to learn what the manual says.

Interventions based on the NARS perspective traditionally focused on investment in public sector organizations engaged in organizing, coordinating, or executing activities expected to contribute to agricultural development, .e.g., national agricultural research organizations, and public institutes of higher learning. Interventions by government and donors were traditionally geared toward strengthening NARS infrastructure, management, and capacity within these organizations, and improving the policy environment within which they operated. The main shortcomings of these interventions are that they implicitly assumed that the generation of information was often enough to induce innovation.

The AKIS approach expanded the NARS approach by connecting the dots between public research organizations, educational institutions and extension services. The AKIS approach focuses on the dynamics of knowledge and technology dissemination through extension (Nagel, 1979; Röling, 1986, 1988). However, the AKIS approach is still largely based on a linear vision of science.

While both the NARS and AKIS frameworks made critical contributions to the study of technological change and agricultural development, they are increasingly challenged by the changing and increasingly globalized context in which technological change and agricultural development are evolving (World Bank, 2006; SC, 2005). This includes such trends as the rapid growth of markets as the main drivers of technological change; new demographic and agroecological pressures; new economic regimes such as trade liberalization and regional trade integration; the growth of private investment in and ownership of knowledge, information, and technology; and expansion of information and communications technology as a means of rapidly exchanging knowledge and information.

Hence, there is need for a framework with which to study innovation processes in developing-country agriculture—a framework that highlights the complex relationships and interactions between old and new actors, and the organizational and institutional learning behaviors and practices that characterize the system. This brings us to the AIS framework.

Recent studies have attempted to describe the innovation systems framework as an analytical perspective that widens the study of innovation beyond the narrower NARS and AKIS concepts, often illustrated by an ever-widening schema of concentric framework-circles (see, e.g., Rivera, 2006). To be sure, all three frameworks examine the notion of “agricultural innovation.” But beyond this point, the frameworks differ significantly, suggesting that attempts to compare them are misleading because of the starkly different analytical emphases offered by the AIS framework.

Importantly, the AIS framework highlights the notion of individual and collective absorptive capabilities to translate information and knowledge into a useful social or economic activity. Thus, an AIS analysis requires an understanding of *how* individual and collective capabilities are strengthened, and how these capabilities are applied to agriculture. This suggests the need to focus far less on the supply of information (brick-and-mortar research organizations and universities, for example) and more on systemic structures and failures within a system, and the practices and behaviors that affect learning and innovation processes. Thus, an AIS might emphasize the absorptive capabilities of individuals to access and apply knowledge and to *change* their routines and attitudes in a way that makes effective use of such knowledge. Here, the analysis essentially unpacks structures into processes as a means of strengthening their development and evolution, further suggesting the need for analytical insights drawn from social psychology, anthropology, and other fields more equipped to study individual and collective behaviors.

Note, however, that the AIS framework does face several methodological limitations in its application to developing-country agriculture (Spielman 2006 a, b). First, while the conventional innovation systems approach relies on a diversity of rigorous qualitative and quantitative methods in studies of industrialized countries, the methodological toolkit employed in the study of developing-country agriculture remains fairly limited. 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).

More often than not, studies are simply *ex post* descriptions of the dynamics and complexities of some technological or institutional innovation. Powerful tools that are systematic, replicable, and consistent methods of analysis that could be used include 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 could bring greater credibility and strength to the study of innovation systems in developing-country agriculture.

Second, the AIS approach has not yet matured to a point where it can inform policy in developing-country agriculture of specific interventions needed to enhance the potential for innovation and improve the distribution of gains from innovation (Spielman 2006a, 2006b). Though exceptions exist, the link between empirical analysis and policy recommendations 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.

Third, few studies in the emerging AIS literature examine the poverty-related effects of innovation processes. In economics jargon, 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.

Despite claims by Hall (2005) that the guiding agenda of AIS is “sustainable and equitable development” unlike its antecedent approaches, there is limited evidence in support of this. 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. There is still very little conceptual or methodological work within the wider literature on AIS to suggest a consistent focus on sustainability or equity.

## **5 Methodological foundations of the innovation systems approach**

The first publications on innovation systems were case studies at the national level that analyzed the interactions between firms, public research institutes (including universities), and institutions, defined as the “rules of the game” (Freeman 1987; Lundval 1992). These first studies essentially described patterns of interaction among large categories of actors (e.g., universities, private firms, and governments).

Later, Cohen and Levinthal (1990) introduced the concept of absorptive capabilities, i.e., the ability of a particular agent to identify and use existing information to innovate. Dosi, Nelson and Winter (2000) present several case studies that explore the nature and development of organizational capabilities. Shavinina (2003) is a comprehensive source on the nature of innovative capabilities in different contexts (e.g., science, art, learning, firms) and on different approaches to build these capabilities.

A related body of literature discusses how organizations learn, a component of the creation of innovative capabilities (Nonaka and Takeuchi, 1995; Von Krogh, Ichijo and Nonaka 2000). The main insight of this literature is that learning in organizations is both an individual and collective enterprise: organizations only learn when their members learn, but individual learning and its sharing with other members of the organization depends on written and tacit rules and organizational cultures.

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) for 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 research and development 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. Ekboir et al. (2006b) analyze the influence of learning patterns, governance arrangements, institutional cultures, and external influences on the consolidation of dynamic innovative capabilities of a Mexican farmer organization that fosters innovation in agriculture. 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. Ekboir et al. (2006a) found that the distribution of exploration capabilities among commercial farmers followed a power law, i.e., these capabilities have a very skewed distribution and cannot be represented by average behaviors. 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.

## **6 New methodological challenges**

As was argued above, innovation processes are complex, with many forces and actors interacting at different scales and dynamics. Management schools recommend focusing more on process than product or outcome in such situations (Narduzzo, Rocco and Warglien 2000). If the main processes and sub-processes that govern the dynamics are well characterized, their successful operation contributes to achieve the overall objectives.

A second consequence of the complex nature of innovation is that no two innovation processes are alike in time and space. For this reason, past experiences are poor guides to the implementation of new programs to promote innovation. Experiences cannot be copied but can only highlight factors that are potentially important in innovation processes. This is the reason why so often best practices fail when applied in a different program or context.

To increase the odds of success, development programs must identify which factors are crucial in their particular case. To identify these factors, each program should develop strong monitoring mechanisms to enable early identification of problems or successes. The monitoring mechanism cannot simply be the collection of a set of indicators; the most essential components are the investment in adequate human resources to interpret the indicators and the establishment of direct links between these resources and the managers of the program so that new initiatives can be tried as needed. Unfortunately, these capabilities are quite rare, resulting in programs that are implemented according to plan, modified only when insurmountable problems arise, and reflected upon only once the program has been completed.

A third and final consequence of the complex nature of innovation processes is that the learning should occur not only at the implementation level but also at the donor and policy making body level. If the appropriate monitoring system is implemented at this level, each program can be seen as a learning experience that contributes both to improve the implementation of all other programs and the ability of policymakers to identify new instruments to promote pro-poor innovation. In the complexity jargon, all programs can be seen as the creation of variation, while centralized monitoring can be seen as the selection mechanism. In other words, each development project should, in fact, be considered an experiment in a protracted action-research program.

Given the complexity of innovation processes and systems, no single method can be used to analyze them. The choice of a method should depend on the objectives of the study.

## **7 New methodological frontiers**

Several methodologies could contribute significantly to the existing innovation systems toolkit. This section examines five possible methods: social network analysis; innovation histories; cross-country comparisons; and game theoretic modeling in the tradition of evolutionary economics.

These methodologies may be grouped into three categories: relational analysis, comparative analysis, and policy process analysis. When combined, these methodologies provide not only a valid, rigorous, and replicable toolkit, but also possess the ability to influence decision-making on key issues in agriculture and rural development—enhancing productivity, increasing food security and nutrition, diversifying rural livelihoods, and reducing poverty. And while several of these methods are data-intensive, others rely on combinations of qualitative and quantitative tools that make them viable even in light of the limited data availability or access limitations that are common to many countries in sub-Saharan Africa.

### **A. Social network analysis**

Social network analysis (SNA) allows researchers to study relationships among multiple actors by providing tools with which to visualize and analyze the relationships (Scott, 2000). SNA was developed by sociologists and further enhanced as an analytical technique by the fields of mathematics and statistics. By combining relational data with mathematical tools and concepts from systems theory, graph theory, and complexity theory, SNA provides critical insight into the relationships between various people, groups, or other entities. In the context of innovation, SNA offers a means not only to characterize, measure, and map relationships between actors, but also to analyze the changes in those relationships and the knowledge flows contained therein (Davies, 2004).

The data used in social network analysis are unique because emphasis is placed on the relationships *between* actors rather than the attributes of the actors themselves. Conventional data, analysis typically focuses on actors, their characteristics, and how they are similar or different. In SNA, the analysis focuses on the pattern of relations across actors. Therefore, the unit of analysis is the dyad—a pair of entities. Dyadic attributes of interest for innovation include social roles, interactions, or flows of information between actors.

For the study of innovation, SNA provides tools that are unique and often absent in many of the cost-based tools. Given the focus on relational rather than attributional data, SNA provides holistic insight into the structure of a system and the interdependence between entities within that system: a “molecular” rather than “atomistic” view of the world (Borgatti, 1998).

For instance, Conley and Udry (2001) used social network analysis to show communication networks among villagers in Ghana. They found that geographic proximity did not determine how smallholders learned; rather, it was the social networks that smallholders were involved with. Muñoz et al. (2004) mapped three networks in which commercial lemon producers from Michoacán, Mexico, participate: technical, commercial and social. These studies identified a few highly connected farmers that increased the network’s navigability. Additionally, these farmers not necessarily were recognized technology leaders.

Temel, Janssen, and Karimov (2003) used a graph theoretical model (a methodology closely linked to SNA) to map the interactions among institutions in the Azerbaijani agricultural innovation system and to derive recommendations to strengthen the system.

## **B. Innovation histories**

Another strand of the literature emphasizes the “innovation history” approach as a method of recording and reflecting on innovation processes as part of wider institutional learning and change (Douthwaite and Ashby 2005; Douthwaite 2002). The approach engaged researchers in a step-wise process of identifying objectives and expectations of stakeholders; defining the innovation; constructing timelines and actor network maps; writing up the learning history; and using the write-up as a catalyst for change.

The approach tends to be internal to the organizations directly involved in the innovation process, but is a potentially useful means of documenting and disseminating analyses that can influence decision-makers in government and other sectors.

## **C. Cross-country comparisons**

Cross-country comparisons of AIS using benchmarks, scorecards, and indices suggest further methodological possibilities. The approach has proven itself as a valuable and effective tool for guiding innovation policy in OECD countries. However, its application to developing countries is fairly novel.

Cross-country comparisons provide a more subtle understanding of technological change in sub-Saharan African agriculture, and the key factors that help explain the potential for continuous innovation in agricultural potential in individual countries. It offers a means with which to differentiate, rank, and benchmark countries; while also providing tools with which to group countries, to demonstrate where interventions can be effective in several countries at once, and to illustrate the potential for cross-country spillovers. Most importantly, the exercise provides policymakers, researchers, and development practitioners with information and analysis that can guide investments and interventions into areas that contribute to the economic, social and environmental goals of the region.

However, there is much reservation about efforts to quantify innovation and develop cross-country comparisons from what are essentially local, context-specific processes that do not lend themselves to comparison (see, e.g., Grupp and Moge 2004). Baltzat and Hanusch (2004) offer some thoughtful insights. Academically-oriented studies of innovation systems did and continue to avoid use of such methods, preferring instead to provide thoroughly descriptive analyses of country-specific structures and their historical, cultural and political contexts. But more recent policy-driven efforts to improve innovative capacity in the European Union and other industrialized countries have led to the use of far more quantitative methods exercises, benchmarking and ranking exercises, and the like. The study concludes that while both approaches can co-exist within the innovation systems literature, more can be done to strengthen the available analytical tools and the application to developing countries.

## **D. Game theory**

Game theoretic modeling based on emerging work in evolutionary economics offers some insight into the value of the innovation systems framework. These models 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 a complex, 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, the interactions among agents and by the institutional landscape that conditions these behavior patterns.

For example, evolutionary models derived from biological population models are described by Maynard Smith (1982) are applied to describe 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.

## 8 Conclusion

Innovation is a complex process; for this reason, it cannot be characterized by simple models that relate quantities of inputs and outputs. As the dynamics of innovation processes are better understood, there is a need for more informative methods—both quantitative and qualitative—to analyze and foster innovation. This paper provides some insight into methodologies that can help improve the study of agricultural innovation systems. These methods address the issues of (a) how agents interact in the production, exchange, and use of knowledge and information within a system; (b) how agents respond individually and collectively to technological, institutional, or organizational opportunities and constraints; and (c) how policy changes can enhance the welfare effects of these interactions and responses.

## 9 References

- Allegri, M. 2002. Partnership of producer and government financing to reform agricultural research in Uruguay. In D. Byerlee and R. Echeverría (Eds.), *Agricultural Research Policy in an Era of Privatization* (pp. 105–121). Oxon, UK: CABI.
- Andersen, E. S. 1994. *Evolutionary Economics: Post-Schumpeterian Contributions*. London: Pinter.
- . 2000. Schumpeterian games and innovation systems: Combining pioneers, adaptationists, imitators, complementors and mixers. Note for the IKE seminar, December 13 (revised April 1, 2003).
- . 2004. *Evolutionary Economics: Post-Schumpeterian Contributions*. London: Pinter.
- Appleyard, M.M., Hatch, N.W. and Mowery, D. 2000. Managing the development and transfer of process technologies in the semiconductor manufacturing industry. In Dosi, G., Nelson, R.R. and Winter, S.G. (eds.) *The Nature and Dynamics of Organizational Capabilities*, New York: Oxford University Press.

- Argote, L. and E. Darr. 2000. Repositories of knowledge in franchise organizations. In Dosi, G., R.R. Nelson and S.G. Winter (eds.), *The Nature and Dynamics of Organizational Capabilities*, New York: Oxford University Press.
- Arocena, R., and J. Sutz. 2002. *Innovations Systems and Developing Countries*. DRUID Working Paper No. 02-05. Åalborg, Denmark: Danish Research Unit for Industrial Dynamics, Åalborg University.
- Axelrod, R. and M.D. Cohen. 1999. *Harnessing Complexity. Organizational Implications of a Scientific Frontier*. The Free Press, NY.
- Bailey, J.R. and C.M. Ford. 2003. Innovation and evolution: Managing tensions within and between the domains of theory and practice. In Shavinina, L.V. (ed.), *The International Handbook on Innovation* (pp. 248-257). UK: Pergamon.
- Balzat, M., and H. Hanusch. 2004. Recent trends in the research on national innovation systems. *Journal of Evolutionary Economics* 14: 197–210.
- Biggs, S. D. 1989. *A Multiple Source of Innovation Model of Agricultural Research and Technology Promotion*. Agricultural Administration (Research and Extension) Network Paper. London: Overseas Development Institute.
- Biggs, S. D., and E. J. Clay. 1981. Sources of innovations in agricultural technology. *World Development* 9(4): 321–336.
- Borgatti, S. 1998. Social network analysis instructional web site. Available at URL: <http://www.analytictech.com/networks/>, accessed on March 1, 2006.
- Buchanan, M. 2002. *Nexus. Small Worlds and the Groundbreaking Theory of Networks*. New York: Norton.
- Byerlee, D. and G. Alex. 1998. *Strengthening National Agricultural Research Systems. Policy Issues and Good Practice*. Washington, DC: World Bank.
- Charles, D. 2001. *Lords of the Harvest: Biotechnology, Big Money, and the Future of Food*. Cambridge, MA: Perseus.
- Chema, S., E. Gilbert, and J. Roseboom. 2003. *A Review of Key Issues and Recent Experiences in Reforming Agricultural Research in Africa*. Research Report 24. The Hague: ISNAR.
- Christensen, C.M. 2003. *The Innovator's Dilemma: The Revolutionary National Bestseller that Changed the Way We Do Business*. New York: Harper Collins Publishers.
- Christensen, C.M. and M.E. Raynor. 2003. *The Innovator's Solution. Creating and Sustaining Successful Growth*. Cambridge, MA: Harvard Business School Press.
- Clark, N. 2002. Innovation systems, institutional change and the new knowledge market: Implications for third world agricultural development. *Economics of Innovation and New Technology* 11(4–5): 353–368.

- Cohen, W.M. and D.A. Levinthal. 1990. Absorptive Capacity: A New Perspective on Learning and Innovation, *Administrative Science Quarterly*, 35:128-152.
- Conley, T. and C. Udry. 2001. Social learning through networks: The adoption of new agricultural technologies in Ghana. *American Journal of Agricultural Economics* 83(3): 668-673.
- Crutchfield, J.P and P. Schuster (eds.). 2003. *Evolutionary Dynamics. Exploring the Interplay of Selection, Accident, Neutrality and Function*. New York: Oxford University Press.
- Davies, R. 2004. Scale, complexity and the representation of theories of change: Part II. *Evaluation* 11(2): 133-149.
- Dosi, G., R.R. Nelson and S.G. Winter. 2000. Introduction: The Nature and Dynamics of Organizational Capabilities. In Dosi, G., R.R. Nelson and S.G. Winter (eds.), *The Nature and Dynamics of Organizational Capabilities*. New York: Oxford University Press.
- Douthwaite, B. and J. Ashby. 2005. Innovation histories: a method for learning from experience. Institutional Learning and Change Initiative (ILAC) Brief 5. Rome: CGIAR.
- Douthwaite, B. 2002. *Enabling Innovation: A Practical Guide to Understanding and Fostering Technological Innovation*. London: Zed Books.
- Ekboir, J. M., M. Muñoz, J. Aguilar, R. Rendon Mendel, J. G. Garcia Muñoz and J. Reyes Altamirano Cardenas. 2006a. *On the Uneven Distribution of Innovative Capabilities and Why That Matters for Research, Extension and Development Policies*. ISNAR division discussion paper no. 7. Washington, DC: IFPRI.
- Ekboir, J.M., G. Dutrénit, G. Martínez V. A. Torres Vargas and A. Vera-Cruz. 2006b. *Las Fundaciones Produce a Diez Años de su Creación: Pensando en el Futuro*. Forthcoming.
- Ekboir, J.M. and G. Parellada. 2002. Public-Private Interactions and Technology Policy in Zero-Tillage Innovation Processes - Argentina, in Byerlee, D. and R. Echeverría (eds.), *Agricultural Research Policy in an Era of Privatization: Experiences From the Developing World*. Oxon, UK: CABI.
- Ekboir, J.M., K. Boa and A.A. Dankyi. 2002. *Impact of No-Till Technologies in Ghana*. CIMMYT Economics Paper 02-01. Mexico, D.F.: CIMMYT.
- Freeman, C. 1987. *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter Publishers.
- Georgsdottir, A.S., T.I Lubart and I. Getz, 2003. The Role of Flexibility in Innovation. In Shavinina, L.V. (ed.), *The International Handbook on Innovation*. UK: Pergamon.
- Hall, A. 2005. Embedding agricultural research in a system of innovation. In CGIAR, *Report of the Science Forum on CGIAR Priorities: Science for the Poor*. Rome: Science Council Secretariat.

- . 2002. Innovation systems and capacity development: An agenda for North-south research collaboration. *International Journal of Technology Management and Sustainable Development* 1(3): 146–152.
- Hall, A. J., and N. G. Clark. 1995. Coping with change, complexity and diversity in agriculture: The case of Rhizobium inoculants in Thailand. *World Development* 23(9): 1601–1614.
- Hall, A., M. V. K. Sivamohan, N. G. Clark, S. Taylor, and G. Bockett. 1998. Institutional developments in Indian agricultural research systems: Emerging patterns of public and private sector activities. *Science, Technology and Development* 16(3): 51–76.
- Hall, A., R. Sulaiman, N. Clark, M. V. K. Sivamohan, and B. Yoganand. 2002. Public-private sector interaction in the Indian agricultural research system: An innovation systems perspective on institutional reform. In D. Byerlee and R. Echeverría (eds.), *Agricultural Research Policy in an Era of Privatization* (pp. 155–176). Oxon, UK: CABI.
- Hall, A., R. Sulaiman, N. Clark, and B. Yoganand. 2003. From measuring impact to learning institutional lessons: An innovation systems perspective on improving the management of international agricultural research. *Agricultural Systems* 78: 213–241.
- Hall, A. J., and B. Yoganand. 2004. New institutional arrangements in agricultural research and development in Africa: Concepts and case studies. In A. J. Hall, B. Yoganand, R. V. Sulaiman, R. S. Raina, C. S. Prasad, G. C. Naik, and N. G. Clark (Eds.), *Innovations in Innovation: Reflections on Partnership, Institutions and Learning* (pp. 105–131). New Delhi and Andhra Pradesh, India: CPHP/ICRISAT/NCAP.
- Ioannides, Y.M. 1997. Evolution of Trading Structures. In W. B. Arthur, S. N. Durlauf and D. A. Lane (eds.), *The Economy as an Evolving Complex System II*. Reading, MA: Addison-Wesley.
- Johnson, B., and O. Segura-Bonilla. 2001. *Innovation Systems and Developing Countries: Experiences from the SUDESCA Project*. DRUID Working Paper No. 01-12. Ålborg, Denmark: Danish Research Unit for Industrial Dynamics, University of Ålborg.
- Kangasniemi, J. 2002. Financing agricultural research by producers' organizations in Africa. In D. Byerlee and R. Echeverría (Eds.), *Agricultural Research Policy in an Era of Privatization* (pp. 81–104). Oxon, UK: CABI.
- Kauffman, S., 2000. *Investigations*. New York: Oxford University Press.
- Kauffman, S. 1995. *At Home in the Universe. The Search for the Laws of Self-Organization and Complexity*. New York: Oxford University Press.
- Lundvall, B-A. 1992. Introduction. In B. A. Ludvall (ed.), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Printer Publishers.
- Maynard Smith, J. 1982. *Evolution and the Theory of Games*. Cambridge, UK: Cambridge University Press.

- Metcalfe, S.J. 2000. *Science, Technology and Innovation Policy in Developing Economies*, Paper prepared for a workshop on Enterprise Competitiveness and Public Policies, Barbados, November 22-25, 1999.
- Muñoz, M., R. Rendón, J. Aguilar, G. García and Reyes Altamirano. 2004. *Redes de Innovación. Un Acercamiento a Su Identificación, Análisis y Gestión para el Desarrollo Rural*. Michoacán, Mexico: Fundación Produce Michoacán.
- Nagel, U. J. 1979. Knowledge flows in agriculture: Linking research, extension and the farmer. *Zeitschrift für Ausländische Landwirtschaft* 18(2): 135–150.
- Narduzzo, A., E. Rocco, and M. Warglien. 2000. Talking About Routines in the Field. In G. Dosi, R. R. Nelson and S. G. Winter (eds.), *The Nature and Dynamics of Organizational Capabilities*. New York: Oxford University Press, N.Y.
- Nelson, R.R. and S.G. Winter. 1982. *An Evolutionary Theory of Economic Change*. Cambridge, MA: Harvard University Press.
- Nickles, T. 2003. Evolutionary Models of Innovation and the Meno Problem. In L. V. Shavinina, L.V. (ed.), *The International Handbook on Innovation*, UK: Pergamon.
- Nicolis, G. and I. Prigogine. 1989. *Exploring Complexity*. New York: W.H. Freeman and Co.
- Nonaka, I. and H. Takeuchi. 1995. *The knowledge-creating Company*. New York: Oxford University Press.
- OECD (Organization for Economic Cooperation and Development). 1999. *Managing National Innovation Systems*. Paris: OECD.
- Olson, E.E. and G.H. Eoyang. 2001. *Facilitating Organization Change. Lessons from Complexity Science*. San Francisco: Jossey-Bass/Pfeiffer.
- Penrose, E. 1959. *The Theory of the Growth of the Firm*. New York: Wiley.
- Peterson, W., G. Gijsbers, and M. Wilks. 2003. *An Organizational Performance Assessment System for Agricultural Research Organizations: Concepts, Methods, and Procedures*. ISNAR Research Management Guidelines No. 7. The Hague: ISNAR.
- Porter, G., and K. Philips-Howard. 1997. Comparing contracts: An evaluation of contract farming schemes in Africa. *World Development* 25(2): 227–238.
- Rivera, W. M. 2006. Transforming post-secondary agricultural education and training by design: Three challenges and a “workforce” proposal for Sub-Saharan Africa. Unpublished manuscript.
- Röling, N. 1986. Extension science: Increasingly preoccupied with knowledge systems. *Sociologia Ruralis* 4(3–4): 269–290.
- . 1988. *Extension Science*. Cambridge, UK: Cambridge University Press.

- Roseboom, H. 2004. Adopting an Agricultural Innovation System Perspective: Implications for ASARECA's Strategy. Entebbe, Uganda: ASARECA.
- Rycroft, R.W. and D.E. Kash. 1999. *The Complexity Challenge: Technological Innovation for the 21<sup>st</sup> Century*. Cassel: NY.
- SC (CGIAR Science Council Secretariat). 2005. *Science for Agricultural Development: Changing Contexts, New Opportunities*. Rome: CGIAR Science Council.
- Scott, J. 2000. *Social Network Analysis. A Handbook*. 2<sup>nd</sup> edition, London: Sage Publications.
- Shavinina, L.V. (ed.). 2003. *The International Handbook on Innovation*. UK: Pergamon.
- Spielman, D. J. 2006a. A critique of innovation systems perspectives on agricultural research in developing countries. *Innovation Strategy Today* 2(1): 25-38.
- . 2006b. Systems of innovation: Models, methods, and future directions. *Innovation Strategy Today* 2(1): 39-50.
- Sumberg, J. 2005. Systems of innovation theory and the changing architecture of agricultural research in Africa. *Food Policy* 30(1): 21–41.
- Sunding, D. and D. Zilberman. 2001. The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector. In Gardner, B.L. and G.C. Rausser (eds.), *Handbook of Agricultural Economics*, Vol. 1A, Amsterdam, New York: Elsevier.
- Temel, T., W. Janssen and F. Karimov. 2003. Systems Analysis by graph theoretical techniques: assessment of the agricultural innovation system of Azerbaijan, *Agricultural Systems* 77:91-116.
- Vieira, L. F., and F. Hartwich. 2002. *Approaching Public-Private Partnerships for Agroindustrial Research: A Methodological Framework*. Coronado, Costa Rica: ISNAR.
- Von Krogh, G., Ichijo, K. and Nonaka, I., 2000. *Enabling Knowledge Creation, How to Unlock the Mystery of Tacit Knowledge and Release the Power of Innovation*. New York: Oxford University Press.
- World Bank. 2006. *Enhancing Agricultural Innovation: How to Go Beyond the Strengthening of Research Systems*. Washington, DC: World Bank.
- Zander, U. and B. Kogut. 1995. Knowledge and the speed of transfer and imitation of organizational capabilities: An empirical test. *Organizational Science* 6: 76-92.