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The CGIAR at a Crossroads: Assessing the role of international agricultural research in poverty alleviation from an innovation systems perspective

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The ILAC initiative fosters learning from experience and use of the lessons learned to improve the design and implementation of agricultural research and development programs. The mission of the ILAC Initiative is to develop, field test and introduce methods and tools that promote organizational learning and institutional change in CGIAR centres and their partners, to expand the contributions of agricultural research to achievement of the Millennium Development Goals.

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Javier Ekboir

Abstract

Globalization, technical change and migration are changing the dynamics of poverty and food production. These factors, combined with a better understanding of the nature of complex processes, are also changing the nature of scientific research, the roles researchers can play in poverty alleviation and the niches in which the CGIAR can operate. While keeping strong breeding and research programs, the CGIAR should devote increasing resources to better characterize the dynamics of poverty, redefine the networks it will use to promote the use of scientific information to foster innovation, link local innovators and researchers with international scientific networks, and help to build innovative capabilities in developing countries. These capabilities should refer not only to scientific research but also to new ways to support innovation and to design and implement poverty-alleviation programs. Finally, CGIAR researchers should adopt new research methods to better integrate into local and international innovation networks.

1. Introduction

The role of agriculture in development and poverty alleviation, including that of agricultural research, has been reevaluated in recent years (World Bank 2007). The discussion, however, has not yet fully addressed how globalization, migration and new technologies have changed the dynamics of poverty and the organization of science, and what role formal research should play in the new juncture. This is particularly true for the Consultative Group on International Agricultural Research (CGIAR) as exemplified by its recent external evaluation (CGIAR Independent Review Panel 2008) and the reform proposal (The Change Steering Team 2008). This paper seeks to contribute to the debate on the CGIAR's future role by analyzing some key issues that have not been properly addressed in the reform process, especially the potential of international public goods as development tools and the roles CGIAR centers can play in fostering innovation.

Poverty alleviation has two benchmarks: achieving food security and affording a healthy life. In the past, greater productivity of food crops resulting from input-intensive technologies was seen as the main tool to achieve both goals. This is no longer the case. An increasing share of rural households derive most of their income from off-farm sources (World Bank 2007); for them food security depends more on access to labor markets and the price of staples than on their own food production. On the other hand, higher yields can eliminate poverty for those subsistence farmers who can become commercial farms; only a small share of rural households, though, seems capable of making the transition (see section 2).

The substantial reduction in poverty observed in the last two decades resulted from rapid growth enabled by integration into globalized markets and from remittances from migrants and not from the expansion of staples in small farms (World Bank 2005; IFAD 2008). Commercial agriculture played an important role in this process. Its expansion resulted from

[1] I would like to thank Jamie Watts, Andy Hall and Martin Piñeiro for invaluable comments on earlier versions of this paper. The usual caveats apply.

the use of marketing and production technologies generated mostly by private firms and sometimes by NGOs. International and public research institutions contributed little to the process (Ekboir et al. 2009). As the limited contribution of public research to agricultural development became evident, donors started to question the effectiveness of their contributions to agricultural research, including the CGIAR and developing countries' research institutions (Byerlee, Alex and Echeverria 2002).

The innovation systems framework has enabled a better understanding of the links between formal research and innovation and has shown the limitations of the linear vision of science which provided the model for the CGIAR; the framework has also helped to identify new instruments to foster economic and social development[2]. Many countries, especially in Europe, and several donors have explicitly embraced the innovation systems framework as the cornerstone of their activities.

For several reasons, however, the CGIAR has not been successful enough in adapting to the new environment (CGIAR Independent Review Panel 2008). First, in contrast to what happened fifty years ago, there is no clear model of what role modern technologies should play in development, in particular, because there are no clear recipes for development (Rodrik 2006). Second, it has been accepted that the joint dynamics of agriculture and poverty have changed (see section 2), and it is not clear what role public research should now play in poverty alleviation given the larger range of actors participating in development and the increased variety of opportunities poor rural households have. Third, because the CGIAR is composed of a large number of actors, each with his/her own agenda, it has been difficult to agree on and implement substantial changes in a system with diffuse governance mechanisms (CGIAR Independent Review Panel 2008). Fourth, the CGIAR was justified as a source of international public goods. When the linear model of science was shown to be incorrect, the idea of scientific public goods as a source of economic growth was also questioned (see section 3.3).

The remainder of this paper is organized as follows. Section 2 reviews the new dynamics of agriculture and poverty, especially the impacts of globalization, high value markets and remittances. Section 3 examines some recent advances in the literature of innovation systems and complexity theories, while section 4 presents a stylized picture of recent changes in research systems. Section 5 discusses the CGIAR's current role; section 6 presents some ideas on how to adapt the system to the needs of twenty first century agriculture; and section 7 concludes.

2. The new dynamics of agriculture and rural poverty

Globalization, technical change and migration have substantially transformed the joint dynamics of agriculture and poverty in developing countries, making some key assumptions that justified the creation of the CGIAR no longer valid.

Prior to the 1980s, poverty was closely linked to agriculture. Since most countries were in the initial stages of urbanization and travel was difficult, farming families worked mostly in rural areas and derived most of their income and food from agriculture. It was only natural to expect that poverty alleviation and growth in agriculture-based countries would come from increased productivity in staples and a few export products (see, for example, World Bank 2007). Agricultural development programs were based on the assumption that productivity

[2] According to the linear vision of science, knowledge starts with basic research; its results are used by strategic and applied research, and end with development and technology transfer. It has been shown that this model only represents a limited range of research areas, especially in chemistry, biotechnology and pharmacology.

jumps could only come from “modern” technologies, designed by scientists and “transferred” by extension agents (World Bank 2006). Because insufficient access by farmers to technical information was seen as the greatest limitation to agricultural growth, important investments were made in research and extension services (Byerlee, Alex and Echeverria 2002). The success of the Green Revolution in South Asia was seen as confirmation of this model. It was not recognized until recently that the impacts of the Green Revolution could not be attributed only to science but to a package that included major investments in infrastructure and subsidized inputs and outputs (CGIAR Independent Review Panel 2008).

After the crisis of the 1980s, most developing countries implemented structural adjustment programs, which included market liberalization, downsizing the public sector and opening new activities to the private sector (Staatz and Eicher 1998). Domestic and international markets became more integrated, diversified and sophisticated, which opened new opportunities and created new challenges for farmers in developing countries (Hellin, Lundy and Meijer 2009). Helped by the new institutional environment, multilateral trade agreements and novel technologies, commercial agriculture in developing countries grew rapidly (World Bank 2007). Additionally, private firms, NGOs and civil society organizations became important actors in development processes, competing with traditional public extension agencies.

Technical change in production, post-harvest, transportation and marketing enabled the expansion of agricultural markets and the emergence of high value agriculture. Most technologies for high-value products were imported and adapted to local conditions by private firms or NGOs (Reardon 2005). Multinational companies sold worldwide the products they developed in their central laboratories, allowing commercial farmers in developing countries to access the latest inputs. The public research and extension institutes from developing countries, in general, did not participate in the expansion of the most dynamic markets, but some researchers participated as individuals (Ekboir et al. 2009). Although the public research institutes and CGIAR centers continued to work mostly in their traditional lines of research, some opened programs in high-value products. Many CGIAR researchers participated in international networks that developed important technological packages for traditional products (see, for example, Ekboir 2002 and Gabre-Madhin and Haggblade 2004). In other cases, they were instrumental in the development of niche markets (e.g., Papa Andina). Their contribution to poverty alleviation, however, seems to have been limited because few small farmers have been able to escape poverty producing cereals (Bourguignon 2006), or because niche markets by nature cannot be massive. In fact, it has been found that only a very small share of small farmers have been able to benefit in the long run from access to high value markets (Hellin, Lundy and Meijer 2009). The limited participation of the CGIAR and public research institutions in the most dynamic agricultural markets led many stakeholders to question their role in poverty alleviation.

Local markets for traditional agricultural products also became integrated into international markets (Hellin, Lundy and Meijer 2009). Small farmers suddenly had to face foreign competition, even if they continued doing what they had been doing for generations. Profitability of traditional products fell, especially for small farmers who did not introduce more intensive technologies. Contrary to what was expected, many small farmers continued producing traditional products despite strong competition from imports. The most accepted explanation for this phenomenon is that poor rural families derive only a small percentage of their income from agriculture, with off-farm employment and remittances being the main sources of earnings (World Bank 2007; Taylor, Dyer and Yunez-Naude 2005). These families still live in the land, but farm only to secure their supply of staples or to produce products that cannot be easily bought and are needed for traditional foods. Thus, the price elasticity of their supply is very low. Higher productivity is still important for the poorest of the poor who have limited insertion in labor markets. For these households, higher yields reduce food insecurity but it is highly unlikely that they will lift them out of poverty (Bourguignon 2006).

Local and distant labor markets also became more integrated. Easier travel and improved financial services meant that people from rural areas could work in distant locations and send remittances back home. In fact, domestic and international migration is becoming the cornerstone of the livelihood strategies of many rural households (Vargas-Lundius 2004). It is estimated that in 2006, 150 million international migrants sent home US$300 billion (IFAD 2008). It has been consistently found that most remittances are invested in education and health (i.e., in human capital that can be used in off-farm employment), housing and only a small proportion in expanding agricultural production (World Bank 2007; López-Córdova and Olmedo 2006; Barret, Reardon and Webb 2001; Davis et al. 2000). The reasons for these investment preferences are poorly understood but they are an indication of the limitations of traditional development policies (including agricultural research and extension) aimed at increasing the agricultural output of most poor rural households.

3. The nature of innovation processes

Innovation depends on the interaction of motivation and ability (Christensen, Anthony and Roth 2004). Globalization, technical change and better infrastructure motivate when they link rural agents (including farmers) to markets. But to take advantage of these opportunities, the agents have to develop appropriate capabilities. This section reviews the complex nature of innovation and innovative capabilities.

3.1. What is a complex process?

Complex processes are characterized by multiple and changing interactions (Crutchfield 2003). The most relevant complex systems for the analysis of the CGIAR are formed by many different independent decision-makers (for example, managers, employees, clients and suppliers), multiple interactions, many feedback mechanisms and random processes. Such systems are known as complex adaptive systems (CAS) (Gunderson and Holling 2002).

Because of its decentralized nature, no single agent can manipulate a CAS or predict how it will evolve in the medium or long term. Even more, the same results can be obtained with different interventions or the same interventions can have very different outcomes; therefore, new approaches are needed for planning and policy-making[3]. There are several methods to do this and discussing them exceeds the scope of this paper (for a detailed discussion see Crutchfield 2003; Gunderson and Holling 2002 and Axelrod and Cohen 1999). One way to influence a CAS is to operate on the dynamics of evolution, especially on variation and selection. For example, a plant breeder knows the characteristics of the parents available to her and selects those she hopes will pass some desired trait to their progeny (e.g. resistance to a given disease). In the early stages of developing a new variety, the breeder usually makes thousands of crosses that do not occur naturally. In other words, the breeder increases variety by making crosses she hopes will raise the probability of obtaining the desired result (as opposed to the totally random natural crosses). With artificial selection, the breeder overrides the natural process of selection via reproductive efficiency by selecting the progeny that displays the desired properties without taking into account their reproductive efficiency. Similar mechanisms are being successfully used to develop complex computer programs,

[3] In fact, predictability of CAS changes over time because of evolving interactions between fast and slow variables (Holling, Gunderson and Ludwig 2002).

synthesize new chemical and medical compounds and develop and implement management strategies for large ecosystems.

The example illustrates a key characteristic of operating on a CAS: contrary to what an engineer (or a researcher working with traditional methods) would do, the “solutions” to “problems” are obtained through a process of directed search without designing them intentionally. On the other hand, scientists who use a rational design approach start by building a detailed model of the problem, and then design a structure that can serve as a solution. The relative efficiency of each method depends on the complexity and stability of the processes upon which it operates and how much is known about it. If little is known, if it changes rapidly or is complex, rational design is less effective because it limits the exploration of the solution space and bets that the explored solution is the most effective. In these cases, the effectiveness of the rational design approach depends more on luck than the management of variety and selection approach. It has been demonstrated that the latter converges on an optimum at least as quickly as the rational design method (Crutchfield 2003).

3.2. What is known about innovation?

We define an innovation as anything new successfully introduced into an economic or social process. Major innovations combine a business model and a technological package (Davila, Epstein and Shelton 2006). Innovations that do not include both components result in minor improvements along an established technological trajectory.

A consequence of our definition is that researchers do not generate innovations but information, either codified (e.g., a paper or blueprint), embedded (e.g., an improved seed) or tacit (e.g., why an experiment failed). This information only becomes an innovation when an agent (e.g., private firms or individual farmers) uses it to improve what s/he is doing. Innovators use different sources of information; most of it, however, does not originate in science but in everyday activities and in interactions with other actors (Faberger 2005). This does not mean that formal research plays no role in innovation; while it may not be quantitatively a dominant factor, it is qualitatively essential because it opens new technological trajectories.

Innovative capabilities depend on the innovators’ absorptive capabilities, i.e., on their ability to use information (Cohen and Levinthal 1990). Rapid adoption of new technologies is not necessarily associated with large expenditures on research and extension, but with the development of absorptive capabilities (Ekboir et al. 2009). For this reason, the dynamics of innovation does not depend on the agents at the forefront of research and technology development, but on the innovative capabilities of the majority of agents. In other words, it is more important to have many agents searching for and using existing information than to have a few sophisticated research institutes in a static society.

Because of the exploding volume of information and the increasing complexity of innovations, no agent commands all the resources needed to innovate; therefore, innovators integrate into networks (Powell and Grodal 2005). The dynamics of innovation networks depend on their complexity and maturity. For simple innovations or mature markets, the networks are loose and members interact mostly formally or through markets because each actor understands the needs of other actors. These networks have been the model for most agricultural programs, including the CGIAR. On the other hand, in the case of new or complex innovations, members interact often and informally to overcome unforeseen obstacles and to build confidence. The need for intense interactions arises because generalized uncertainty about the new technologies and their market potential prevents effective contracting (Christensen, Anthony and Roth 2004).

The effectiveness of innovation networks depends on their ability to facilitate the search for and exchange of information and resources. Technically, this is known as the network’s navigability. Navigability depends on the existence of “central” actors (e.g., highly connected actors) interacting among them, which, in turn connect different clusters of network members. It has been shown that a few central actors can greatly increase the network’s navigability (Watts 1999).

The emergence and consolidation of innovation networks depends on a number of factors, among which a catalyzing agent is one of the most important (Ekboir 2002). This agent induces other partners to invest time and resources in the network. Once the network is consolidated, the importance of the catalyzing agents diminishes, because other actors are more willing to participate when the benefits of participation become clearer, and the interaction rules are known to all partners. The role of the catalyzing agent is different from that of linking agents. The catalyzing agent facilitates the emergence of the network while the linking agent increases the connectivity, even in mature networks. While the catalyzing agent is essential in the early life of a network, the linking agents are important through the whole process.

3.3. The nature of organizational innovative capabilities

Organizational capabilities are important because actors usually innovate by interacting in formal or informal networks. These capabilities cannot be bought or easily copied; thus, they have to be built with sustained investments, selection of appropriate specialists and project leaders, and strong commitment by the partners (Christensen, Anthony and Roth 2004). Organizational capabilities are embedded in individuals and in the organization’s technology, structure, strategies, routines, culture and coordination procedures (Argote and Darr 2000). Even though innovative organizations must have at least a few innovative individuals, this is not required for the vast majority of its members; what is required is that the organizations create an environment in which innovative individuals can express their abilities and influence other members (Christensen, Anthony and Roth 2004).

Organizations depend on their innovative capabilities to respond to changes in the technological, economic and social environments. Innovative capabilities are built by learning, i.e., by creating knowledge. The specialized literature differentiates between information and knowledge (Quantas 2002). Information is organized data (e.g., published materials, blueprints or physical objects), while knowledge is the use of the information to create unique interpretations of reality. Because of its personal nature, two actors can learn different things from the same information, or the same thing from different types of information. Knowledge is very difficult to share while information can be disseminated quite easily.

Because the information stock is complex, diverse, short-lived and fast-growing, learning requires strong capabilities to search for useful information and to digest it to create knowledge (Ekboir et al. 2009). These absorptive capabilities depend on exogenous and endogenous factors. Economic stability, development, the nature of competition and the interactions between firms and research institutes are important exogenous factors; the endogenous factors include organizational cultures, investments made in the search for and adaptation of information, quality of the personnel and mechanisms to socialize knowledge.

The understanding of organizational innovative capabilities has major consequences for the nature and role of the CGIAR. One of the major justifications for its existence has been the generation of international public goods (Alston, Dehmer and Pardey 2006; CGIAR 2008 and 2006). The public goods generated by the CGIAR are technical information, either embodied (e.g., seeds), or disembodied (e.g., publications and agronomic recommendations)[4]. Pure public goods do not require any special effort or skill on the side of the receiver of the services of the goods (Faberger 2005). But to use technical information, innovators have to invest substantial resources to develop absorptive capabilities. In other words, while information may be free, its use is not; spillovers only occur when agents have invested in their absorptive capabilities.

4. Changes in the organization of science

Globalization, new regulations and advanced technologies are redefining the international research environment. Increasing interdependence between knowledge-based economies implies an ever-expanding international flow of technology, scientific knowledge and know-how. The better understanding of complex systems and the development of methods to operate on them are also changing the organization of science in four ways. First, the linear vision of science highlighted the preeminence of theoretical research over applied work. The examples presented in section 3.1 show that in fact, both approaches are complementary. Even more, overreliance on theoretical work in a CAS can actually be a hindrance, because it constrains the exploration of new research approaches and potential solutions.

Second, research systems must be flexible to react to new problems and opportunities. But individual institutions cannot react fast enough because of inertias (Christensen, Anthony and Roth 2004). Flexibility can only be achieved with enough variation in the system. In other words, it is necessary to have a system with many good institutions that can form multi-institutional teams to solve emerging problems; in fact, this has been one of the major strengths of the American research system (Kraemer 2006), and one of the major problems the CGIAR faces (see section 5). Third, effective research systems resulted when researchers interacted closely with innovative agents (Faberger 2005), but the CGIAR has had problems developing stable partnerships with others, beyond those with National Agricultural Research Institutes (NARIs).

Fourth, formal research has traditionally been conducted by stable teams within an institution and discipline; Gibbons et al. (1994) called this organization the mode 1 of research. This mode describes the CGIAR in its early days, except that instead of just one institution, the centers coordinated breeding networks. In mode 2, teams are multidisciplinary, multi-institutional (often involving researchers from the public and private sectors and other stakeholders), increasingly distributed in distant locations and relatively ephemeral, as they are formed to respond to specific issues. Action-research is an example of mode 2 research in which farmers and other actors actively participate in the organization and implementation of projects.

The flexible organization that results from mode 2 allows innovators and research institutions to react rapidly to emerging technological needs or opportunities. It must be stressed that the main difference between modes 1 and 2 of research is not what is researched but how it is done. How to switch to mode 2 is the most important challenge the CGIAR faces today.

[4] A seed is not a public good since it is rival and excludable. The fact that CGIAR centers distribute seeds for free does not change their private good nature. The public good is the knowledge of how to combine parents to develop a particular seed. International germplasm banks are also private goods. Although these banks serve the whole of humanity, they can in principle refuse to give seeds to a particular agent and, since the use of a seed precludes others from using exactly that same seed, they are rival.

5. A review of the CGIAR

The original design of the CGIAR reflected the success of the Green Revolution, the fact that most of the poor lived off of agriculture (see section 2), agricultural technology polices revolving around NARIs and a linear vision of science. In its early years, the CGIAR had a very clear and narrow goal: to stave off hunger by increasing the productivity of staples in small farms (Alston, Dehmer and Pardey 2006). Thus, it gave highest priority to breeding improved varieties of cereals. In the 1970s, about two-thirds of CGIAR resources were allocated to research on rice, wheat and maize. High priority was later given to improving the quality of diets through research on food legumes and ruminant livestock (Anderson 1998). The initial success of the CGIAR resulted from the collective effort of high quality researchers working on a narrowly focused problem (i.e., plant breeding) and policymakers providing the economic incentives to induce adoption (CGIAR 2008). In this sense, the CGIAR in its early days repeated the formula that made the US research system highly effective (Kraemer 2006) and was similar to other successful programs, such as SEMATECH[5].

Following the linear vision, the first CGIAR centers were the central nodes of breeding networks that also included the NARIs selecting locally adapted varieties, extension services taking the seeds to the farmers and sometimes policy makers providing economic incentives to induce adoption. In 1971 the donors and centers expanded their activities under six broad program thrusts: research to increase productivity of food production; management of natural resources; assisting countries in designing and implementing food, agricultural and research policies; capacity building by training and strengthening national agricultural research systems (NARS); germplasm conservation by collecting and classifying genetic resources and maintaining genebanks and other means of conservation; and building linkages between NARIs and other components of the international agricultural research system (Anderson 1998).

The new activities were added with little consideration for what these changes meant for the type of science the CGIAR should conduct or how it should be carried out. Several factors reduced the effectiveness of the expanded mandate. First, in contrast with the initial focused mission, the new objectives were more diffused and spread the resources over more activities. Second, breeding is essentially different from research in other agricultural fields. Breeding relied on international networks that facilitated exchanges of germplasm; in other words, they increased diversity combined with an effective selection mechanism. The other activities did not form similar global networks and worked with a smaller set of partners because their research was more location-specific, and no agreement emerged on what were the best methods to study those topics. Additionally, while the CGIAR centers could find good partners for breeding in some NARIs, it was more difficult to find them in other research areas. Finally, it was not clear what advantage international researchers had in more location-specific research (CGIAR 2006).

Third, in the 1980s research policies in developed countries underwent a major transformation which included a shift from “blind” funding of research institutions to project funding where policymakers set more specific targets; in other words, policymakers reduced their support for academic (i.e., curiosity-oriented) research and increased it for research oriented to social and economic needs (Lepori et al. 2007). This change was accompanied by a demand for research institutions to show the impacts of their activities, as evidenced by the discussions that followed the 1993 US Government Performance and Results Act (Kraemer 2006). The

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[5] SEMATECH is the world's catalyst for accelerating the commercialization of technology innovations into manufacturing solutions (Source: http://www.sematech.org/corporate/index.htm)

CGIAR also followed this path, and, in the mid-1990s began to transform itself into an output- and impact driven system (Kassam 2006). CGIAR funders as well followed these trends, which increased the center's transaction costs, hampered long terms research programs (CGIAR Independent Review Panel 2008) and forced the centers to commit important resources to demonstrate their impact (Bellon et al. 2006); the new approach resulted in a number of impact studies (see, for example Byerlee and Moya 1993 and Evenson and Gollin 2001).

In the 1980s and 1990s, the conceptual model of research systems in developing countries underwent major changes. The concept of the NARIs was replaced by the NARS, which also included universities and other agricultural research institutions; in the 1990s the NARS was replaced by the Agricultural Knowledge and Information System (AKIS) which included research, education and extension (Byerlee, Alex and Echeverria 2002). While these models still reflected the linear vision of science, they showed that the CGIAR had to develop new interactions with a more diverse set of partners, many of which had weak research capabilities (see, for example, Spielman et al. 2008). In parallel, private firms and NGOs started to develop commercial agriculture, usually importing technical and scientific information. In the 2000s, the concept of the Agricultural Innovation System began to gain acceptance; the main consequence of this transition was that public researchers in national or international centers were no longer seen as the central actors of agricultural growth, but just another source of information or a potential partner in innovation networks.

Several stakeholders criticized the NARS for their lack of participation in the emergence of high-value markets and the failure of modern seeds to eradicate poverty. This led to a substantial downsizing or closure of public research and extension institutions (Byerlee, Alex and Echeverria 2002). The CGIAR centers found that they could no longer rely exclusively on weakened traditional partners, and started to work with private firms and NGOs.

In these years, the CGIAR's mandate expanded even more. The new activities included managing research networks to facilitate research performed by others, some in conjunction with CGIAR centers (Plucknett, Smith, and Özgediz 1990); rehabilitating seed stocks in nature- or war-ravaged countries; promoting no-till, and developing niche markets. Because the expanded mandate had to be met with reduced budgets, breeding programs were further scaled back (Alston, Dehmer and Pardey 2006). The expansion in the number and types of potential partners the centers could work with made most of their networks even more diffused and required developing new types of capabilities and interactions. Some of these activities have been branded "development less directly related to research" (Alston Dehmer and Pardey 2006, pp. 324). It should be noted, though, that this statement reflects a mode 1 vision; if properly conducted, these activities could involve new approaches to mode 2 research (for example, action-research or manipulation of variation and selection as explained in section 3.1).

After realizing the potential of high value agriculture in poverty alleviation, several centers started to work on diversification and development of niche markets to the point that high value agriculture became one of the CGIAR's priorities (CGIAR 2005). This type of work, however, differs greatly from that done on staples and livestock. Because high value markets are more complex, newer and fast changing, development of the business model is, at least, as important as the agronomic package (Reardon 2005). When their mandate committed them to work in low value products (e.g., maize or rice), some centers explored the use of their crops as inputs in the production of high value products. But the CGIAR centers did not have the expertise to develop agricultural value chains or to research these topics (Science Council Secretariat 2007). Over time, a few centers (e.g., CIP and CIAT) developed some of these capabilities, but, then, they became more similar to NGOs and increasingly different from traditional research centers. This does not mean that these activities should not be done, but it is not clear what advantage the CGIAR has in this area relative to specialized NGOs (e.g., Technoserve[6]) or universities with strong international programs such as Michigan State University or Wageningen.

The main challenge agricultural research in the CGIAR now faces is that the networks it formed in the past are no longer viable because most NARIs have weakened, and the new partnerships that need to be created require new models of science, new partners and new patterns of interaction. However, because of the complexity of innovation processes and the rapid changes science is going through, there are no clear recipes for how to build these partnerships. Complexity theories and the innovations systems framework can provide guidance on how to approach the problem (see below).

Social science (including economics) has always played a subordinate role in the system. Initially, these programs were created to study the factors that determined farmers' adoption of improved varieties (Cernea 2006). When funding declined in the late 1980s, the priority shifted to measuring the centers' impact to justify their work to the donors (Bellon et al. 2006). In recent years, several centers have started programs to analyze the nature of agricultural innovations, but these efforts are dispersed and have not reached a critical mass (e.g., CIP, IFPRI and ILRI). In addition, learning how to promote innovation among small farmers requires new research routines (Ekboir et al. 2009), and few centers have developed expertise in them.

The CGIAR's two specialized social sciences centers (ISNAR and IFPRI) require special consideration. ISNAR was mandated with helping NARS; as the vision of the role of NARS in development changed, ISNAR found it difficult to define a niche that was also acceptable to donors and important stakeholders (Ozgediz and MacNeil 2006). Recognizing the new environment, ISNAR started to explore the concept of innovation systems; this new direction, however, was strongly criticized by the CGIAR Technical Advisory Committee and the External Program and Management Review, and contributed to its closure as an independent centre (ISNAR 2002)[7].

This criticism, however, reflected the linear vision of science, and a lack of understanding of the emerging needs of innovation networks in developing countries. Although NARS weakened, the importance of other actors in the innovation system increased (see sections 2 and 3). These actors, including the international centers and the CGIAR itself, also needed support to strengthen their capabilities to manage innovation processes and to develop instruments appropriate for the new economic and social environment. Most organizations, however, have great difficulties in developing new capabilities on their own (Christensen and Raynor 2003; Smit 2007). To overcome these hurdles, the specialized literature recommends creating bridging structures that help organizations find useful information, mediate between researchers and other areas of the network and identify internal and external barriers to innovation (Davila, Epstein and Shelton 2006). ISNAR was starting to work along these lines when it was transformed into an IFPRI program.

IFPRI was created to research food policies and provide policy advice. From its beginnings, it developed a culture that valued publications in scholarly journals above more applied work and interactions with policymakers in developing countries. Because many studies contained policy lessons applicable to several countries, they were branded as international public

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[6] TechnoServe helps entrepreneurial men and women in poor areas of the developing world to build businesses that create income, opportunity and economic growth for their families, their communities and their countries. (Source: http://www.technoserve.org)

[7] It must be also recognized that serious management problems contributed to ISNAR's closure (ISNAR 2002).

goods, but they are no different from many papers published by other international organizations, think tanks or universities. For most of its life, IFPRI established weak links with other CGIAR centers and policymakers in developing countries and could have been a department in a good university. While in recent years IFPRI has introduced new programs with input from social sciences other than economics, the center still has an academic culture in accordance with the linear vision of science (see section 4).

Additionally, IFPRI's culture resulted in a narrow exploration of policy alternatives and overreliance on a restricted theoretical body (i.e., essentially microeconomic theory and quantitative methods). For example, its research policy recommendations have not evolved in the last twenty years (see, for example, Alston, Dehmer and Pardey 2006), and are based on the linear vision of science and mechanistic models (e.g., DREAM[8]). In other cases, the policy recommendations are based on uncorroborated assumptions. For example, Ruben and Pender (2004) assert the existence of diminishing returns to investments in research. Diminishing returns are assumed in static microeconomic models in order to derive an analytical solution. In dynamic, complex models, however, there is no reason to assume diminishing returns. Because the interaction between positive and negative feedback loops is continuous and changing, returns can alternatively be increasing and decreasing (Holling, Gunderson and Ludwig 2002).

In 2003 the CGIAR launched its first Challenge program, a new approach to building partnerships. Challenge programs provided a flexible mechanism to structure multidisciplinary, inter-institutional teams to address specific issues. If properly managed, they could have been the basis for conducting mode 2 research. Two reviews by the Science Council and the CGIAR Secretariat (Science Council 2007 and 2004) and the recent independent review (CGIAR 2008), however, indicate that the CGIAR still evaluates the Challenge Programs from a linear perspective.

In 2004 the Science Council was given more power to oversee the work of the centers, especially, setting the system's priorities (CGIAR 2005). In the following years it tried to align the centers' activities with these priorities. The urgency to align the centers and Challenge programs was reiterated in the system's independent review (CGIAR Independent Review Panel 2008). A similar strict alignment could have serious consequences in the future CGIAR. As was explained in section 3.1, complex processes are difficult to understand and predict. Therefore, instead of setting clearly defined strategies and priorities, actors operating in such environments should use learning strategies to identify emerging trends and to explore alternative solutions. Fifteen independent but coordinated centers can be a very effective structure to implement a strategy of decentralized experimentation with centralized learning. In fact, some centers have already implemented innovative projects in response to identified opportunities (for example, CIMMYT's work on no-till); what the system lacks is an effective and flexible structure to learn from these projects.

An additional problem is that the model of research behind the priorities set by the Science Council still reflected a linear vision of science (see Science Council 2005) and seem to have been an important input in the definition of potential research areas for the redesigned CGIAR. Forcing the centers to revert to such a model would isolate them even more from innovation networks and hamper innovation. This problem is compounded by the performance measurement system which evaluates the centers by their achievement of predetermined goals (Science Council Secretariat 2006). The literature on contracts (MacLeod 2007) and innovation management (Davila, Epstein and Shelton 2006) have shown that

[8] DREAM, or Dynamic Research Evaluation for Management, is a tool for evaluating the effects of agricultural R&D (Source: http://www.ifpri.org/dream.htm)

predetermined goals and incentives induce actors to engage in minor innovations along known technological paths. To foster the development of major innovations, the optimal policy is a system that rewards past performance based on a clear understanding of the drivers of innovation (MacLeod 2007).

6. Assessing the CGIAR reform process from an innovation systems perspective

The reform process currently under implementation is based on the assumption that public goods can make a positive contribution to poverty alleviation and the sustainable use of natural resources. The public good the CGIAR produces is scientific information, either embedded in seeds or disembodied as papers and recommendations[9]. This information, however, is useful only if poor farmers have the capabilities to find it and absorb it (see section 3). For this to happen, two conditions are needed. First, poor farmers have to be willing to become commercial farmers and they have to be capable of doing it. As was shown in section 2, however, there are clear indications that many poor rural households prefer not to become commercial farmers. Therefore, the CGIAR should clearly define what its poverty alleviation goals are: helping the poorest of the poor to increase food security, assisting poor farmers who have the potential to become commercial farmers, supporting commercial farmers so that they create employment and increase food availability or all of them. Once the target population is identified, appropriate approaches to reach it must be developed. Given the complexity of poverty alleviation, however, no clear recipes to do this will ever exist and appropriate learning mechanisms should be created (see below).

The second condition is that researchers address farmers' needs or technical opportunities with methods that facilitate absorption. A crucial component of these methods should be that both farmers and researchers participate in innovation networks that foster information sharing, so that researchers can understand the farmers' operating conditions and the farmers can access scientific information. Meeting these two conditions requires less consideration to what is researched and more to how the research is done, especially, how researchers interact with stakeholders.

The reform proposal is based on two key principles about how research should be conducted: consolidation of research activities in a few programs and defining accountabilities through program performance contracts. The effectiveness of these changes will depend on how they are implemented. As was explained in section 3, complex processes are characterized by unforeseen outcomes and constantly evolving interactions; even more, because causalities are non-linear, it is difficult to attribute outcomes to particular interventions. Contracting in such contexts is extremely difficult because there is no clear link between performance and outcomes (MacLeod 2007; Sykuta and Parcel 2003). Even more, operating in complex environments requires evolutionary approaches and strong learning mechanisms (Crutchfield 2003). In other words, for the contracts to be effective, they will have to be flexible and reviewed often to allow exploration of alternative approaches.

The CGIAR's new structure does not include a mechanism for institutional learning. The Independent Science and Partnership Council (ISPC) is expected to provide core scientific advice related to system strategy, priorities and assessment of scientific quality and impacts of CGIAR-led research but is not expected to interact continuously with the centers' senior management and researchers to assess new research methods, facilitate information sharing

[9] The CGIAR also conducts other activities that are not public goods such as information portals, direct support and training. Most documents, however, still justify the system as a source of international public goods.

and the implementation of pilot-projects. Even more, the advice provided by the ISPC will still have to be absorbed by the CGIAR, and for this to be successful the system should develop absorptive capabilities.

It is unlikely that the system will be able to develop absorptive capabilities without a sustained effort. To build these capabilities, the specialized literature recommends creating dedicated, permanent structures for organizational learning with strong support from the top management (Smit 2007; Davila, Epstein and Shelton 2006; Christensen, Roth and Anthony 2004). Recently, some donors (e.g., DFID and IDRC) and centers started to explore programs to develop innovation capabilities (e.g., the intercenter ILAC Initiative hosted by Bioversity), but these efforts have been isolated and have not been sufficiently backed by the CGIAR and centers' authorities.

Institutional learning structures on their own are unlikely to provide enough flexibility to attain the systems' goals. Individual institutions (including the CGIAR centers) usually cannot change fast enough to address emergent issues (Christensen, Roth and Anthony 2004), but a diversified, multi-institutional system can (Kramer 2006). In other words, the CGIAR should tap more into good researchers from a wide range of institutions that manage programs that may be outside the centers' capabilities and narrow mandates. The key for such strategy is a strong executive office that can recognize problems, allocate resources and identify actors (including researchers) that can contribute essential assets. Such strategy could be played by a strong CGIAR Consortium Office that is not restricted to manage center performance agreements.

Effective institutional learning strategies require appropriate planning that recognizes the complexity of the system's mandate and that most problems can be solved with different interventions. Rigid priority setting would miss emerging issues and reduce the exploration of alternative solutions. Designing flexible planning strategies and incentive systems that can deal with complexity, however, is beyond the scope of this paper; the interested reader should consult Christensen, Anthony and Roth (2004) and Axelrod and Cohen (1999).

The innovation systems framework can also help to identify other actions the international centers could undertake in addition to mode 1 research (i.e., production of international public goods). Given the increasing complexity of innovation and research processes, the centers could become catalyzing and linking agents in global networks. Thanks to their global connections, the centers can help to identify successful experiences in many countries, link innovators with sources of scientific and technical information in distant locations (in particular, advanced research institutions), use action-research to help adapt foreign experiences to local conditions and promote the emergence of global research networks. In this way, the CGIAR would become a central node of a system of decentralized experimentation with centralized learning. An example of such work was the development of a no-till planter for small farmers involving actors in Bolivia and India, process in which CIMMYT played a key role (Ekboir 2002). These activities should not be evaluated with traditional research indicators such as peer reviewed publications, but rather by their contribution to the consolidation of networks and to building absorptive capabilities of innovative agents. Social Network Analysis and new approaches to performance assessment can be used to develop appropriate indicators (see, for example, Spitzer 2007).

The exploration should also include the expansion of traditional breeding networks. Sixty years ago, these networks were centered in the CGIAR, and included mainly public and some private breeding programs, seed companies and extension services. Today, the public actors in developing countries have seriously weakened, leaving the CGIAR without its main partners. While new partnerships are emerging (in particular with small seed companies and NGOs), the breeding programs should explore more actively novel arrangements to better support the diffusion of improved seeds.

Finally, the role of social research in the CGIAR should be reevaluated. Many centers do not have a critical mass of social scientists; even more, the number of scientists has been falling and they were never fully integrated into the centers core activities (Cerenea 2006). Social scientists from all centers could strengthen their collaborations to achieve critical mass for the creation of a learning structure to explore new ways to a) foster the emergence of innovation networks that involve ARIs and developing countries teams and identify the roles the international centers should play in them, b) promote institutional change in their centers, c) help the centers' researchers from other disciplines to shift to mode 2 research; and d) given the failure of traditional training programs to build lasting capabilities in the public sector, build the capabilities of other actors in innovation systems. A research program to better understand the joint dynamics of agriculture, globalization and migration to redefine the CGIAR's role in poverty alleviation should also be established.

7. Final remarks

The dynamics of development and poverty are rapidly changing due to globalization, migration and technical change. In the last two decades, many poor rural households have diversified their livelihood strategies, seeking more off-farm income and high value agriculture over increased production of low value products. Most of the technologies used in high value agriculture were developed by private firms and distributed by the private sector or NGOs; public research and extension institutions had very limited participation in the most dynamic markets. Additionally, several studies have found that growth is the most effective way to reduce poverty, which questions the strategy of supporting low value agriculture by small farmers as a development instrument.

These facts are starting to change the perception of the effectiveness of traditional development policies, including the role agricultural research should play in poverty alleviation. In particular, the concept of innovation is replacing the traditional research and extension continuum. Innovations are developed by networks that include private firms, farmers, technical advisers and, in some cases, researchers; in fact, most innovations do not originate in formal research but in economic or social processes. The networks' ability to innovate depends, among other factors, on their absorptive capabilities, i.e., their ability to search for and use existing information, whether it is scientific, commercial or organizational.

The innovation systems framework questions the traditional role assigned to the CGIAR, i.e., the production of international public goods. The information generated by the international research centers can only be used by those actors that have invested to build their absorptive capabilities. In other words, while the information is free, its use is not. This observation helps to explain the limited expansion of agriculture in poor households despite the fact that many of them receive remittances from migrants.

The CGIAR defines itself not just as a technical but rather as a development research institution (Cernea 2006). To fulfill this vision, the system will have to adapt to the new socioeconomic environment, facilitating the interaction between global research and local innovation networks, and helping innovation networks to access technical information and to create it when it is lacking, in other words, strengthening its role as a bridging agent. It will also have to expand the centers' flexibility, so that they can explore new instruments to foster innovation.

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