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Technology Generation, Adaptation, Adoption and Impact: Towards a Framework for Understanding and Increasing Research Impact[1,2]

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Introduction

International agricultural research, technology generation, transfer, adoption and impact (IARTGTAI) constitute components of a system that has evolved from a relatively simple structure in the 1960s to a complex network in the late 1990s. Its functioning is of great international interest. Despite major successes on the food front, there are still 850 million people who earn less than a dollar a day and go to bed hungry. Many studies of research, adoption and/or impact in agriculture exist, but they tend to look at specific aspects of the scientific and technology processes, such as priority setting or research impact. The recent changes in the science and technology processes and the resulting present structure have not been analyzed sufficiently yet as organizational innovations intended to alleviate market failures with a view to achieve specific social objectives. The innovations form part of a larger global science and technology process consisting of multiple actors, each with a different set of interests. A broader evolutionary framework offers an opportunity for a clearer understanding of the relationship between sources of technical change in agriculture, and the spread of its adaptation and adoption by producers and agroindustries.

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[1] A paper prepared for a reader on Food Security, edited by Dr. Manfred Shulz of Freie Universität Berlin.

[2] This paper builds on an earlier paper by Uma Lele, Shiva S. Makki, Javier Ekboir and Edward W. Bresnyan, Jr. "Accelerating Adoption of CGIAR-NARS Collaborative Technologies: Towards a Framework for Understanding and Increasing the CGIAR Impact", May 21, 1997, The World Bank, 1818 H street, NW, Washington, DC., 20433, unpublished. We appreciate Michel Petit's comments on an earlier draft.

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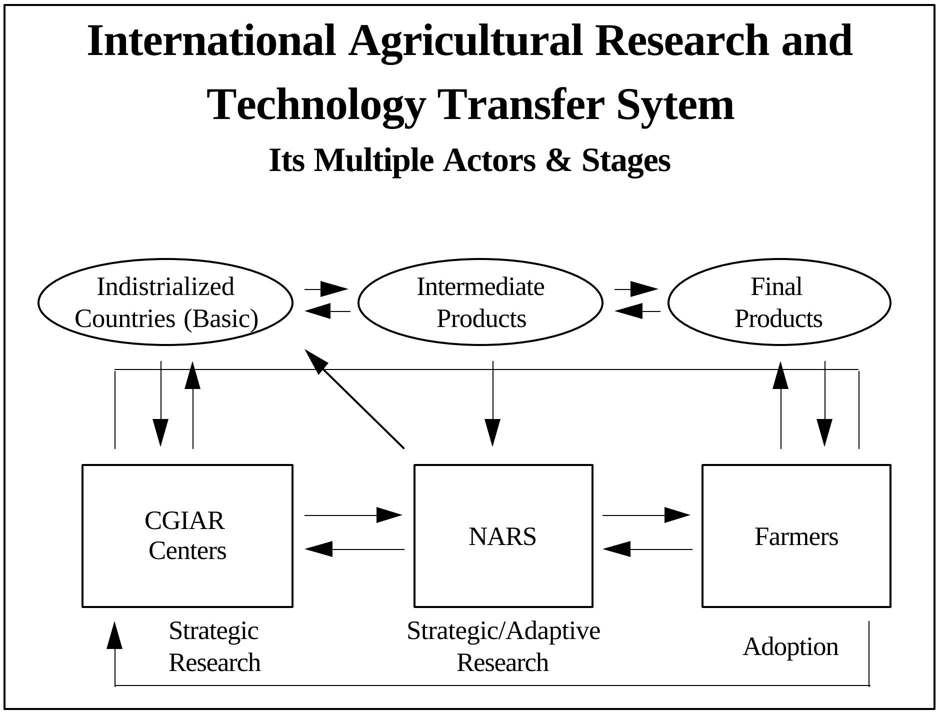

Figure 1

In this paper we look at IARTGTAI as a complex social process in which actors (donors, international research institutions, the ministries of finance and agriculture, researchers, research administrators of the National Agricultural Research Systems (NARSs), as well as producers, industries and users), each with different interests interact, whether by design or by default. These interactions result in a number of research and technological outcomes, which in turn offer further technological options (Figure 1). Several of these options are developed further by the same or different actors into new lines of research or finished products. Other options are "abandoned" either permanently or temporarily.[4] The process is not linear. Rather it involves the passage of information over time in several directions. Feedback from other participants in the scientific and technology processes assists researchers and research managers to establish and revise their research agendas. The results of the scientific and technology processes in any single period of time are the consequences of past interactions among the different groups participating in them. Besides, non-technology factors influence the spread of technology in a fundamental way, including effectiveness with which each individual component of technology generation or transfer processes such as policies and institutions operate. Better understanding of the forces that condition the interactions among actors, and the consequent evolution of IARTGTAI can provide useful information for research policies, funding and priority setting in agricultural research and technology transfer.

[4] The structure of the DNA was identified in 1953; however, no applications for this discovery were found until the late 1980s.

The actors in the Consultative Group for International Agricultural Research (CGIAR) system interact mainly through non market mechanisms, and each type responds to a different set of objectives and constraints. Major changes in the global economic and research systems are affecting the environment in which the CGIAR operates leading to more active consultation with the private sector, the non governmental organization (NGO) community, and the national agricultural research systems (NARSs) of developing countries. These changes dictate that IARTGTAI be viewed in an evolutionary and systemic perspective to understand the implications of these changes for future CGIAR research and technology transfer policies.

Several frameworks have been used to analyze the evolution of public sector research systems. Particularly in the case of the U.S. the competitive interest group model is said to offer the best explanation (Guttman 1978; Evenson and Rose-Ackerman 1985; Marcus 1987; Huffman and Evenson 1993; Khanna, Huffman and Sandler 1994). These types of "interest group" decision models have not been applied to the international agricultural research system of the CGIAR or to the research systems of developing countries which form an important part of the CGIAR system. Other authors have used the induced innovation model which suggests that allocation of resources to public sector research is influenced by relative prices (Hayami and Ruttan 1985). The validity of the assumptions underlying these "competitive" models needs to be assessed in the real world context in light of the recent developments in the field of institutional and organizational economics which have increasingly questioned the underlying assumptions of the competitive model.

A comprehensive analysis of the system also requires consideration of the technological possibilities available at each particular stage, the interactions among actors in evaluating these possibilities, including those whose interests are not expressed as direct contributors (such as funders or voters), and therefore actors who are not usually included in the analysis of technological development (trade associations), or the groups such as poor farmers or future generations. Demands of these groups for technology products and policies tend to be poorly articulated, yet they constitute important clients of public sector research. New approaches to the analysis of technical change (new institutional economics, evolutionary economics and ecological economics) provide a framework for the study of many of these interactions. The principal argument made in this paper is that IARTGTAI involves multiple actors and multiple feedback loops in several directions rather than a unitary “laboratory to farm approach” assumed in the traditional approaches to technological change. The outcomes depend fundamentally on the nature of interactions among these different actors and explain differences often observed in the spread of the same technology and its ultimate impact in similar agroecological areas, e.g., between the Indian and Pakistani Punjab on wheat or within India among different states on sorghum, or with regard to maize in sub Sahara Africa.

Section 1 discusses the limitations of the current analytical approaches in understanding the relationship between processes and outcomes and offers an alternative framework. Section 2 explores the changing global environment for research and technology transfer. Section 3 discusses the changed climate affecting support for the CGIAR system.

1. An Alternative Framework to Study IARTGTAI

Recent theoretical developments in economics (e.g., institutional economics, evolutionary economics, ecological economics) offers possibilities of a broad, dynamic, evolutionary approach and a new conceptual framework to reflect the role of different interest groups in the processes of technology generation and transfer and their ultimate impact. (Coase 1972; North 1991; Nelson 1995; Lynn et al. 1996; Dosi 1997; Wright 1997).

The many interactions among different actors leading to processes and sub-processes cannot be sufficiently characterized with the use of a competitive model. The latter requires well-defined objectives, assumes that agents have full information to pursue those objectives, and choose the correct way to achieve them. It also assumes that there are no scale economies. Furthermore, the model typically focuses on outcomes, such as research investments, their efficiency or productivity, rather than on the processes, i.e., decision making rules and sequences which individuals and organizations follow, and which in turn affect outcomes through their effect on processes.

A well known framework for analyzing research in agriculture, for instance, is the induced innovation theory (Hayami and Ruttan 1985). It posits that changes in relative prices, e.g., between agricultural and nonagricultural commodities, or among factors of production such as labor and capital, will induce investments in agricultural research. The theory implies the scientific and technology process as a linear sequence, (from basic research to applied and adaptive research, transfer and, adoption); with one stage following the previous one in a smooth transition. Researchers and administrators respond to market signals to identify research needs (i.e., institutional signals and non monetary constraints are only relevant if they are reflected in relative prices). Given that technologies being adopted today may be a result of research initiated up to 30 years ago, it is not clear which market signals are appropriate (Dosi 1997). Finally, productivity increases can occur due to research which was not necessarily induced by demand; for instance, progress in basic research has stimulated strategic, applied and adaptive research in the fields of veterinary and human medicine, and plant and animal breeding, which would not have occurred otherwise.[5]

The induced innovation theory is also an explanation of outcomes after all "failed" alternatives were "discarded" over time. In that sense the approach confuses the outcome of a process with the process itself and does not inform us as to whether technology adoption and research

[5] Some examples include genetics research on DNA, remote sensing research, geology research on soil formation and characteristics, mathematical and physics research in developing computers, space research leading to food production under zero gravity conditions.

impact would have been greater had certain other alternatives been selected. Understanding of the whole research and technology transfer process seems necessary to better understand which alternatives were rejected and why with what possible effects on the menu of technologies that emerged and spread. This requires a more comprehensive characterization of the research production function.

Other extensive set of studies show very high rates of return to agricultural research, even after adjusting for certain biases in estimations. But they do not illuminate us on how research processes may affect returns. Besides, they do not inform us on the impact of research on institutions, human capital or the environment. We propose the use of an evolutionary approach to the analysis of science and technology generation and transfer. The major building blocks of this approach are (Nelson 1995; Dosi 1997):

- The explanation of why something exists rests on how it became what it is; in other words, the evolution of processes (firms, markets, policies, etc.) matters and is path-dependent.

- Agents have limited information and understanding of the environment in which they live, and the paths the environment will take in the future; additional information cannot reduce the uncertainty about the future. Because of these limitations, agents are not assumed to maximize profits but to follow decision rules that are applied over an extended period of time.[6] Bounded rationality is the rule.

- Agents are always capable of discovering new technological and institutional opportunities, some of which will eventually be adopted. These changes, conditioned by the "external" process (markets, regulations, etc.), perform as selection mechanisms.

- Imperfect understanding, path dependence, and idiosyncratic learning routines imply persistent heterogeneity among agents, even if facing the same information and the same "objective" opportunities.

- Aggregate phenomena (market outcomes, adoption of new technologies, etc.) are the collective outcome of the individual actions and interactions characterized by bounded rationality.

This approach has been extensively used to analyze the evolution of specific industries (Burgelman 1996; Smith et al. 1992; Winter 1990), technology policies (Georghiou and Metcalfe 1993; Metcalfe 1995; Metcalfe 1994), and to develop new management tools at the

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[6] A relatively new body of literature analyzes decision processes in the presence of irreversibilities (Dixit and Pindyck 1994). In this case, agent are assumed to maximize over time a function that balances the expected benefits of a decision with the expected cost of making the wrong decision and having to reverse it. This process is observationally equivalent to bounded rationality; agents change actual policies sporadically.

firm level (Barnett and Burgelman 1996). The evolutionary approach has not yet been used to analyze the generation, transfer and adoption of agricultural technologies.

The new evolutionary framework has far-reaching consequences for the study of science and technology generation, its differential transfer and impact. First, the explicit recognition of the complexity and the dynamic nature of IARTGTAI means that its evolution cannot be measured by a single variable, but requires a number of indicators which may show opposite behaviors, e.g., a particular research may have failed in achieving high rates of return but may have contributed substantially to learning by doing or institutional development. A methodology for deriving implications from these contradictory results has to be developed. A more explicit exploration of what is measured, and whose values and indicators are used to measure impact (whether those of donors, scientists or farmers) would improve understanding of what determines which lines of research are pursued, why, and their potential impact, make better uses of the existing data sets often collected for other purposes, improve the choice of indicators and their measurement, while also helping to focus the priority setting process by providing more information to scientists and funders of research. A good example is the extent to which scientists in the past focused on yield growth alone while ignoring the many complex requirements of farmers dictated by labor availability, harvesting, processing, storage and marketing. These latter have consistently been shown to have affected the spread of technology and its impact. The other example is the possible difference in the objectives of donors and potential beneficiaries of new technologies. In the case of dairy development in India, two radically different viewpoints are found in the literature about the impact of commercialization and modernization in the dairy sector on women. Critics argue that these processes have generated hidden costs and increased the workload of women who provide most of the labor. They argue that modern dairying reduces women from '*doers and deciders'* to *'doers only'* (George 1991). Advocates on the other hand argue that the dairy development program in India known as Operation Flood provides an opportunity for women to improve their economic and social status (Somjee and Somjee 1989). The literature also draws attention to the social and cultural constraints which hinder active participation by women in modern dairying which technology development and transfer alone can not address (Kumar 1997, World Bank Forthcoming).

Second, case studies conducted with this approach would collect and analyze a wider range of variables than that usually reported in the literature. In addition to the traditional agronomic and economic variables (e.g., yields, area planted or income), institutional and organizational indicators would be included (e.g., convergence between the goals of donors and the needs of users, information of communications systems, the state of universities and research institutions, or the development of intellectual property rights). Third, *a priori* models for organizing the information (such as the rational optimizing agent operating in a static environment) would be replaced by more flexible approaches that include the historical and social aspects of the process and enable reaching a more explicit convergence among the goals of the different actors so as to make the research priority setting and technology transfer process more efficient and impact greater or wider.

Lynn et al. (1996) propose the concept of innovation community to refer to the organizations directly and indirectly involved in the development and dissemination of new technologies. Within an innovation community, agents are categorized into groups with similar characteristics. Belonging to any particular group may be voluntary (as in the interest group theory), or the involuntary consequence of performing a particular function in the community (such as being a poor farmer). Groups interact in a complex web of social and economic relationships, having a specific set of competencies and performing a specialized role defined by a set of variables (e.g., size, economic and political power, degree of centralization or authority structures).

An important role in such a system is the coordination of activities, functions, roles, and contributions (Lynn et al. 1996). Coordination includes the passage of information (including funds and priorities of other agents), facilitating the interaction of agents within and between hierarchical structures, participation in negotiation processes, and definition of incentive structures.

Some agents organize themselves to gather and disseminate information through the community, information being any signal (e.g., market information, orders from authorities, funds) that helps other agents in their decision process. The extent to which how information is converted to knowledge and communicated (e.g., within and between research institutions and extension agents), and how decisions are made can be critical to the performance of the system and central to understanding sources of growth (Stiglitz 1984). Yet this remains one of the least explored areas in empirical research on research and technology transfer. Communities that have better communication channels are more successful because technology generation and diffusion are network phenomena with substantial scale economies (Wright 1997). As technology becomes global, active participation in the international technological network becomes more profitable for countries with limited research capabilities. As Wright (1997) explains "... much of the benefit seems to derive, not from the generation of new, original technologies, but from maintaining the technical capacity to monitor, test, evaluate, and implement innovations originated elsewhere, selecting those that suit the local situation best."

The reverse side of this process is that unequal access to knowledge, or unequal capacity to convert information into useful knowledge, has become a major source of disparity. With the spread of new communication technologies, including increasing reliance on the internet, this source of disparity may likely increase. Countries with weak infrastructure and/or weak NARSs cannot take advantage of advanced technologies in part because they cannot screen new processes and products, and in part, because of lack of know-how and resources to protect or effectively deploy intellectual property. The economies of scale in technology scouting provides new opportunities for the CGIAR system because it has the potential to allow countries with relatively week NARSs to benefit from the new technologies, and to increase the efficiency of the technology network for all participants, from developed as well as developing countries.

The performance of the technological community is conditioned by the nature of its hierarchical structure. In developed countries the community has many communication channels among interest groups, while in developing countries communication channels have tended to be both more concentrated and often blocked. Indeed, in many developing countries access to information has been greatly constrained by the hierarchy in which scientists operate. Again, access to internet is changing that state of affairs in some respects, but may not do so in another, i.e., to the extent that access to computers themselves are determined by the hierarchical position of scientists rather than the extent to which they can make use of the information. Critics argue that in structures such as those, even in developed countries, powerful groups benefit and outcomes are short term oriented, disregarding long term environmental or equity considerations. But the recent changes in the content of public funded research toward natural resource management (NRM), food safety and biotechnology in developed countries reflect a change in the strength of competing interest groups (e.g. the increased power of consumer and environmental groups and scientists relative to that of agricultural producers and processors) suggesting that the evolution of the research community is not determined only by the dominant groups at any given point in time, but rather by the changing nature of those interactions among a multiplicity of actors and events. What implications does this way of looking at the system have for the CGIAR system given that the CG centers and the NARS are each not only at a different stage of development but are evolving at different rates in an international context which is currently very dynamic in several respects?

2. The Changing Environment for IARTGTAI

The CGIAR system currently involves annual commitments of around US$300 million, employs approximately 900 scientists and constitutes about 4 percent of the global agricultural research budget.[7] The circumstances in which the CGIAR system was created in the early 1970s have changed dramatically in many ways. The CGIAR was created to make up for an important market failure, i.e., adaptation of technologies generated in developed countries to address the problems of poverty and hunger in developing countries, and particularly the transfer of technologies to resource poor farmers, with whom the laboratories of the CGIAR centers often worked directly. Consistent with the way research was organized more generally at the time, the CGIAR was conceived as a unitary, relatively top-down system, in the sense of a lab to land approach. The recent changes in IARTGTAI present new challenges and opportunities for the CGIAR system. Among these changes are:

- The CGIAR's objectives, mandate, products and clients have all become more diversified. The most recent CGIAR mission calls for reducing poverty and ensuring food security

[7] In 1995, the donor community included 23 industrialized countries, 13 developing countries, 12 international and regional organizations, and 6 foundations. They contributed, respectively, 64 percent, 2 percent, 32 percent, and 2 percent to the CGIAR research funds (see Table 1).

through increased productivity, ensuring sustainability of natural resources, conserving biodiversity, and developing capacity of the NARSs. The number of CGIAR institutions has increased from four in 1971 to sixteen in 1997. Its clients now include NARSs, NGOs, farmers and their organizations and the private sector of both developed and developing countries. CGIAR's products now range from research methods and analytical tools, to training and institutional development, as well as being a role model in the type of multidisciplinary research conducted on crop and NRM technologies.

- Even though the number of donors has increased to over 50, the growth of financial support for the system has slowed while the composition of that support has changed. A smaller share of the contributions now comes from the US, and increased share from Europe and Japan. The share of the World Bank has increased to compensate for the US reductions (Table 1).

- The membership of developing countries has increased from 2 to 15, although the share of developing countries' contributions in the total is only 2 percent, explaining their expanding and yet still limited voice in the CGIAR system.

- Developing countries' NARSs have grown stronger in their research capacity (Bonte-Friedheim and Sheridan 1996). From monolithic publicly dominated organizational structures, NARSs are evolving into diversified systems with stronger participation of universities, NGOs, and the private sector (both local and international). However, the rate of change in various parameters is different among different countries.

- Regional organizations of the NARSs are becoming important players increasing the possibility of exploitation of scale economies in applied research, which are weaker at the global level where the CGIAR centers operate. For example, development of more environmentally sensitive technologies is highly location specific research, with few scale economies. This calls for an increased “layering” approach in research and technology transfer including greater role for the regional and sub-regional research organizations.

- The desire for balanced budgets is making developed and developing countries alike to cut down on research expenditures and focus more sharply on priorities and research efficiency.

- The increasing strength of the international agricultural research system, which has entailed considerably stronger role for the applied and adaptive (and in some cases even strategic) research by the NARSs, now allows a two-way transference of technology between developed and developing countries. Whereas the early CGIAR varieties involved greater content of germplasm and technology from the north, Pardey et al. (1996) recently estimated the increased benefit of the CGIAR system to industrial countries: an investment of US$134 million (Centro Internacional de Majoramiento de Maiz y Trigo (CIMMYT) and International Rice Research Institute (IRRI)) in rice and wheat improvements led to a return of US$15 billion for the U.S. economy alone. The same applies to the benefits of stronger NARSs. A number of major natural resource management (NRM) technologies, such as zero tillage and integrated pest management (IPM), come from farmer innovations in developing countries and have spread to developed countries. Additionally, NARSs scientists in developing countries are leading in developing hybrid rice, baby corn, long staple cotton and management of acid and sodic soils with potential benefits to developed countries.

- Intellectual property rights, liabilities, and government-industry relations are changing leading to a rapid growth of private sector research, and their supply of agricultural technologies and inputs. Market-oriented trade policies have enhanced the role of trade and commerce, changing the setting in which issues of food security, poverty, equity, NRM, and environmental sustainability are discussed. Particularly challenging for the CGIAR is the increasing importance of intellectual property rights (IPR). If CGIAR centers do not patent their research, private researchers will do it, preventing the transference to NARSs and resource poor farmers; this means for research to be freely available, paradoxically, it may have to become private.

- An important question for the future is the extent to which the market will develop technologies suitable to the conditions of poor farmers. A related issue is that the traditional products and services of the CGIAR are likely to be under pressure from the growing importance of the private sector. Often these new commercial technologies involving, for example, genetically engineered crops, entail different contractual arrangements with farmers, different technological trajectories, with substantial implications for patterns of competition, interindustry dynamics and market changes than those developed by the international agricultural research centers (IARCs). Importation of plant genetic material or acquisition of national seed companies by multinational corporations under the new liberalized investment regimes is, for instance, having a quicker, more dynamic impact on the sources of technology than the management of the resource system. However, these changes are more likely to benefit commercial crops and commercial producers rather than food crops produced by the small and marginal farmer which has been the focus of the CGIAR. Since present choices affect future growth performance and income distribution, and conditions the decisions that societies will have to make down the road, comparison of available technologies developed by the CGIAR, NARSs and the private sector is increasingly needed to anticipate future outcomes. For instance, the use of Monsanto's no till technologies may mean reliance on and availability of the chemical "Round-up." Other no till technologies may call for changes in the farming systems, each with different implications for the use of modern inputs, information sets, etc. As the current Anti-Trust debate on computer technologies in the U.S., and the related economic theoretical literature is revealing, power of individual industries could determine future choices in research, technologies and their impacts including on the extent of intra-industry competition and impact of technologies.

- The agricultural research establishments in developed countries display at least five characteristics of diversification, leading to many different sources of research and technology for users which developing countries are likely to emulate, namely: (1) the share of private sector agricultural research, technology development and transfer increases relative to that of the public sector; (2) the share of public sector agricultural research in agricultural GDP increases, typically from less than 1% in developing countries to between 2% to 4% in Canada, U.S., Australia, and to up to 10 percent if private research is taken into account, meaning substantially greater investment in research, technology development and transfer relative to developing countries both in absolute and relative terms (Pardey et al. 1995); (3) the role of universities increases vis-à-vis that of public sector research institutions; (4) the relative (not absolute) share of the public sector declines over time, with the public sector increasingly focusing on the "quintessential public goods research" i.e., research benefits of which are long term, broadly derived and difficult to capture for the private sector; and (5) the role of the local and regional research and technology transfer systems increases in applied and adaptive activities relative to that of the federal/central government, with the latter playing a more strategic, catalytic role in stimulating research in the overall national research system (Lele 1996). It is interesting to view the international agricultural research system in this context.

3. The Technology Community of the CGIAR System

The main structures through which agents participate in the IARTGTAI community to which the CGIAR belongs are authorizing environment, operating capacity, and customers. Some groups participate in several of these structures; e.g., large NARSs contribute to the CGIAR budget and influence the priority setting process (authorizing environment), participate in joint research projects (operating capacity), and use technologies developed by CGIAR centers (customers). (Figure 2)

3.1. The CGIAR's Authorizing Environment

Those who fund and oversee the CGIAR system constitute the authorizing agents. This group has become more diversified since the creation of the system; also, individual agents have a more diverse set of objectives due to considerable pressure from their legislatures, universities, producer groups and (increasingly) the NGO community. They are demanding greater evidence of impact of the research they fund. The increasing diversity of the authorizing environment is the consequence of a new awareness both in developed and developing countries of the existence of inarticulated demands, such as technologies for poor farmers and NRM, and the increased capabilities of developing countries NARSs.

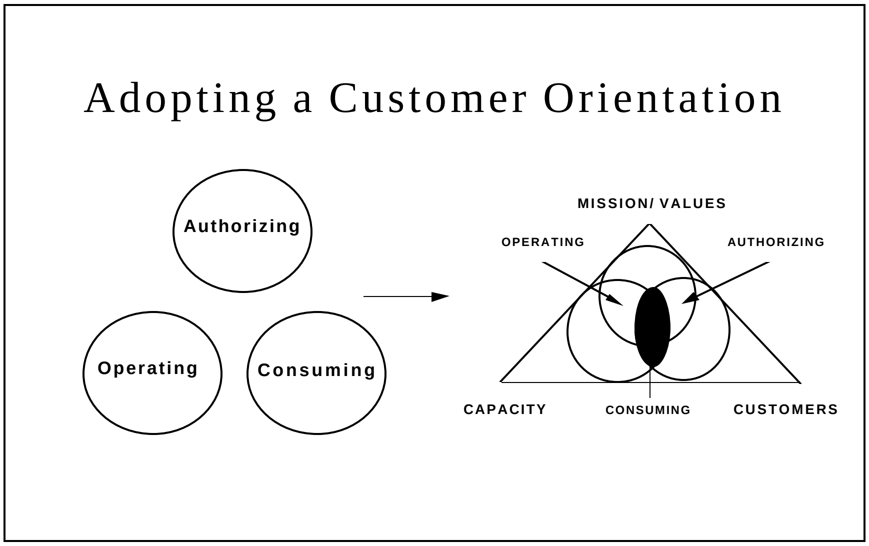

Figure 2

The greater diversity of the funding community makes it more difficult for each donor to achieve its objectives. When specific donor objectives do not receive priority from the CGIAR's Technical Advisory Committee (TAC), the donors fund special projects. The proliferation of special projects reached a peak of US$59 million in 1995, or nearly 20 percent of the total budget (Table 1). The special projects became a parallel priority setting mechanism, in which the formal mandate of the CGIAR was partially overridden by funders. The problems created by conflicting mechanisms led the system's Chairman to suggest re-engineering the system, which involved (1) a matrix approach to research priority setting and its funding by donors; (2) increased consultation with donors, NARSs, NGOs and the private sector; and (3) focus on other agricultural research efforts including particularly the advanced countries' NARSs in the context of which the CGIAR system's mission is expected to be articulated and conducted.

The declining rate of growth of donor support has been a result of a number of factors, including reduced international food prices, the end of the cold war, the growing view of agriculture as the villain of the environment, the pervasive skepticism about the roles of the public sector and foreign aid, and budget constraints in industrial countries. Increased contributions from multilateral organizations, particularly the World Bank, have enabled maintenance of expenditures in real terms (Table 1).

The system's Chairman has also encouraged increased membership of developing countries, which more than doubled to 15 members since the early 90s. Although their financial contributions to the system were less than 2 percent of the total in 1995, developing countries make substantial in-kind contributions. A majority of the approximately 60,000 CGIAR germplasm accessions come from developing countries. Their NARSs now house two-thirds of the global agricultural scientific community, contributing to the production of the improved, more tropically derived germplasm issued by the CGIAR.

The poor in developing countries that the CGIAR aims to benefit have often had little voice in their countries' public decision making processes. Similarly, their governments have, in the past, had little voice in the governance of the CGIAR system. However, this state of affairs is changing rapidly. Democratization in developing countries and increased access to information has opened the way for greater participation of the institutions that represent the interests of the poor in developing countries as well as in the CGIAR system. Their economic growth and gains in human capital have also made their increased role in the CGIAR system imperative. These developments were reflected in the International Fund for Agricultural Development (IFAD)-led NARSs consultation process initiated in 1994, leading to the global consultation at the 1995 CGIAR meeting and the formation of a Global Agricultural Forum in 1996. Notwithstanding these gains, even large farmers in developing countries do not yet exercise sufficient political pressure to influence the research budgets of their countries. Furthermore, in spite of the recent reforms in the CGIAR system, developing countries continue to have a limited voice in the governance of the CGIAR system, in part reflecting their low financial contributions to the system.

Research expenditures in developing countries to date have come mostly through public finance. With structural reforms, several developing countries are trying to provide greater voice to the clients of research including farmers, agroprocessors and exporters, diversifying sources of finance as well as research priority setting procedures. Farmer lobbies will have to finance a larger share of agricultural research in developing countries for budgetary reasons. Public sector rationalization and shortages in the operating budgets has meant that even the strong research systems such as those of China, Argentina and Brazil have to generate more revenues from the sale of products, services and research results. A positive aspect of this development is the need for research centers to connect with their customers. The negative result is that the earned resources from commercialization are not ploughed back into the research system, thus leading to a growing tendency to increase income earning activities, at the cost of research. Developed countries in the meantime are proceeding rapidly with patenting a large pool of new knowledge in the private sector which would be increasingly less accessible to developing countries. The extent to which developing countries continue to upgrade their physical, institutional and human capital to take advantage of the rapidly expanding scientific network will determine the extent to which they partake in the new scientific revolution. Even the more advanced developing countries have not yet caught on to the full implications of these changes for their research policies and strategies. It is in part a result of lack of sufficient information among the policy makers of developing countries regarding the nature of the scientific revolution and its implications for them. The problem for the poor low income countries is even more serious. Often, it is not simply one of information but of finances and political will.

One of the important tasks of the authorizing environment is the definition of research and transfer priorities. Priority setting and resource allocation within the CGIAR system takes place at two interrelated levels. At the system level, the TAC identifies priority areas (e.g. commodity research, NRM research, biodiversity) and provides the broad criteria or guidelines for resource allocation among the priority areas. TAC periodically revises priorities of the system to account for changing CGIAR mission, goals, and mandate, emerging trends in world agriculture, evolving scientific capacity in developing countries, and stakeholders' concerns (McCalla and Ryan 1992). For instance, the 1992 report of the TAC emphasized NRM research, based on ecoregions and land use systems, while the 1996 report focused on poverty alleviation, sustainable food security, and NRM while perhaps under emphasizing the ecoregional focus. Individual research centers then set priorities through their strategic and medium term plans (Kelly et al. 1995; Walker 1996).

3.2. The CGIAR's Operating Capacity

The individual IARCs and the NARSs comprise the operating capacity of the CGIAR system. The greatest strength of the IARCs has been their humanitarian mission, a problem solving, interdisciplinary approach, access to global scientific knowledge, materials and institutions, and the convening power that the combination of these factors provides to the IARCs. The system has been an important catalyst for partnerships with the NARSs of both industrial and developing countries. Individual centers have been able to produce important products and services which the authorizing environment has been willing to underwrite by its funding. With the declining number of CGIAR scientists and the increased number of CGIAR centers the capacity of the CGIAR system to achieve impact is far more constrained now than previously, calling for wider partnerships with other research and technology transfer partners (Serageldin 1997).

The operating capacity of the IARCs represents an important socially concerned supply-side of technology generation. Publicly oriented scientists can contribute to decisions as to what technological responses are scientifically possible given resource constraints, their perception of the needs of their customers, and longer planning horizons.

The increasing strength of developing countries NARSs both in absolute terms and relative to the CGIAR is creating a more diversified environment with increased opportunities to cater to local needs. Several NARSs in developing countries (e.g., Brazil, India, China) have gained strength in the last 30 years and are now conducting basic, applied and adaptive research. Producers associations are also conducting adaptive research in association with national research institutions or by themselves. Some of the strongest NARSs in developing countries are transferring technologies to weaker NARSs with similar agroecological conditions.

Some analysts argue that there is much scope for improvement in the division of labor among the CGIAR centers and the NARSs. For instance, it is estimated that nearly 40 percent of the total wheat varieties released in developing countries in the last three decades came from CIMMYT-NARSs collaborative research, 25 percent from indirect transfers and 10 percent from country-to-country spillovers (Maredia and Eicher 1995). For crops such as wheat, where international transferability of research is large, developing countries could allocate more resources at the margin to search for international research outputs so as to maximize spillins. This implies an increasingly important role for both regional research collaborations and NARSs in building sufficient capacity to capture spillins. Efficient access to the information network for weaker NARSs and the coordination of activities among NARSs becomes more difficult as the system's complexity increases due to increasing returns to investment in these areas. While the relative advantage of the CGIAR in direct research falls with the increased specificity of the problems tackled, its advantage as a coordinating organization and as a diffuser of information increases.

3.3. The CGIAR's Customers

The consuming environment represents the demand side of the system. The producers and consumers of research all constitute distinct facets within this complex customer mix. They include NARSs, universities, NGOs, private sector researchers, as well as input suppliers, extension agents, processors, and producers (both in developed and developing countries). The choice of the term customer instead of the traditionally used term beneficiary has profound socioeconomic significance (Denning 1994). Beneficiary denotes a patron-client or a paternalistic relationship that the genesis of the CGIAR implied (Baum 1986; Lele and Coffman 1995), while customer implies an improved decision maker.

The customers' community has also become more diverse over time. The stronger NARSs in developing countries are demanding research inputs to be used in their own research programs while interacting more actively with developed countries' NARSs (e.g., the Global Research on the Environmental and Agricultural Nexus (GREAN) Initiative) and other developing countries' NARSs (e.g., Programa Cooperative para el Desarrollo Tecnologico Agropecuario del Cono Sur (PROCISUR)). Even though producers' associations and NGOs are also becoming active demanders of research products and transfer services, there are no formal channels through which latent demands can be represented, nor methodologies through which they can be identified. On the other hand, many smaller NARSs remain donor dependent and financially more hamstrung by their inability to effectively retain their researchers, even though their human capital base is stronger now than before.

The greater diversification of the customer community has allowed for a more active interaction with the authorizing environment and the operating capacity. The CGIAR system was created when the donor community realized the potential for large yield increases in developing countries; in other words, it was a top-down organization. Presently, different organizations negotiate directly or indirectly with the authorizing environment their demands for research in a more open political climate. In this way, users of technology that had previously been excluded from the decision process are now able to influence the allocation of resources.

4. The New Roles for National and International Innovation Communities

The above discussion implies many diverse origins and paths of technology generation and adoption, some of which begin with the CGIAR system, move to the NARSs institutions, and finally, arrive to the producers. Others originate in developed countries' universities, multinational corporations or in the developing countries' NARSs, and move to the CGIAR. A customer-oriented process can ensure the feedback loops from the producer to the NARSs and the CGIAR system and information sharing throughout the system, including where necessary, input from the advanced countries' research.

Differences in the organization of research and transfer in different countries make it a challenge to forge effective linkages, not only between the CGIAR system and NARSs (including the private sector), but also among the NARSs of developing countries, between those of developed and developing countries, and farm households, producers and consumers. On the other hand, this diversity increases the potential for mutually beneficial interactions

This paper analyzed the different interests represented in the decision making bodies (TAC, boards, etc.), and the ways in which these bodies gather information and support from both the users as well as the suppliers of technology, including technology transfer agents. A continuous and at some stages informal negotiating process takes place where priorities are negotiated among the interested parties based on mutual feedback. The extent to which the inarticulated demands of poor farmers, consumers, other users of natural resources, and future generations is represented in these decision bodies is an important issue still to be resolved.

At early stages of the system, the donors identified the latent demands of poor farmers in developing countries (which also happened to coincide with the self interest of developed countries engaged in the Cold War) and funded the system. Presently, the range of inarticulated demands is large and represent conflicting objectives, e.g., many traditional yield increasing technologies (traditionally in research) affect soil structure, and, consequently, future production (future generations' objectives); in other cases they do not have particular characteristics demanded by users (taste, processing or storage qualities demanded by the users of technologies).

To the extent that NARSs of developing countries intend to prioritize some of those demands, they will have to increase their contributions to the IARTGTAI system in order to influence the decision making process. Other demands (such as the right of future generations to use exhaustible natural resources) will probably continue to be represented by NGOs, both in developed and developing countries. Since the NGOs do not have resources to finance the research by themselves, they influence the system indirectly by pressing the donors. As all demands have to be negotiated in the process of setting objectives, some present donors will probably reduce their contributions (seeing that their interests are not being served as they hoped for) while others, including developing countries, will have to increase their support to have greater influence in the final decisions. Adequate support for the system in the future will depend on the ability of the authorizing environment to compromise on the individual objectives and on the capacity of the CGIAR system to convey its mission and specific research goals to the "right" donors. If the negotiation process is transparent, then the balance of power within decision making bodies becomes explicit, and remedial actions, if needed, can be taken.

Decisions about research priorities are made simultaneously at different levels and these decisions are interconnected. For example, priorities in the CGIAR system are affected by decisions of donors, who need to promote the agenda and policies that maintain the support of their constituencies. But, in deciding their own policies, donors also interact with the CGIAR system and NARSs and receive feedback from the users in the process. In brief, the priority setting process entails formal and informal negotiating mechanisms where the different actors use their comparative advantages in articulating supply and demand for research, as well as in the conduct of the IARTGTAI functions.

An additional advantage of making the negotiation process more transparent is that the potential benefits are more readily perceived by the participants. Organizations or interest groups that are presently not participating in the process would find out that the potential benefits are large enough to justify the effort required to participate. Even though some of the present participants could lose interest in the CGIAR if the decision process becomes more participative, the likely outcome is that more customers will find it beneficial to participate, with the result that the scope of the system would be enlarged and international support would increase. The CGIAR's priority setting efforts have evolved considerably when viewed from this perspective, but are perhaps not yet fully informed by the views of the customers in the process whose lives the research process aims to impact.

Final Remarks

This paper presented an alternative framework to analyze agricultural research, technology generation, transfer, adoption and impact based on a premise that understanding the process of research and technology transfer has significant implications for the extent, speed and the spread of impact. This framework is based on the premise that IARTGTAI is a complex process that evolves in a non linear iterative manner due to the interaction of a number of actors in several directions. Some of these are conditioned by the evolution of variables exogenous to the system. Particularly relevant for the understanding of this process is the study of the nature and the extent of the hierarchical structures and the channels that convey information and convert it into knowledge and decision making through the system.

The evolutionary approach contrasts with other studies that have concentrated on the measurement of a few easily measurable and largely economic indicators of outcomes, e.g., productivity growth. They tell us little about the relationship between the processes and outcomes. In addition to advocating a wider scope for case studies of individual technologies, the evolutionary approach can use cross country and cross technology comparative studies to provide a better understanding of the interactions among factors that limit, or enhance the speed of technology development and transfer by better understanding the types of interactions outlined above.

The framework was used here to sketch the evolution of the IARTGTAI system to which the CGIAR belongs. The main features that characterized the process are:

- An increasingly diversified set of objectives. In addition to reducing poverty through the development of advanced technologies, the objectives now include ensuring sustainability of natural resources, conserving biodiversity, and developing capacity of the NARSs.

- Due to a larger number of actors participating in the authorizing environment, priority setting at the system level requires more complex negotiations, making it more difficult for each participant to objectively understand the factors that ideally should influence the research agenda so as to have maximum impact.

- Even though the number of researchers in the CGIAR centers has fallen, the operating capacity of the system as a whole has increased because NARSs in developing countries have become stronger. Also, regional organizations are becoming important instruments to capture economies of scale in research. However, with rapid advances in science, there is need to establish a different set of partnerships with industrial countries including with the private sector, universities etc., to work out a new set of comparative advantages.

The sketch presented here is still incomplete and needs further development. The aspect of the analysis which needs further exploration relates to the evolution of the hierarchical structure of the authorizing environment, and how the changing environment is likely to affect the division of labor among the institutions of advanced countries, the CGIAR centers, NARSs and other actors in research and technology transfer. Better understanding of these processes will help to improve research and technology transfer priority setting both at the level of individual NARSs as well as the CGIAR system as a whole and improve our understanding of the factors that determine impact. This is particularly relevant for understanding the impact of technologies, the benefits of which are indirect, take a long time to manifest themselves, require a change in traditional practices (e.g., NRM technologies or technologies addressing problems of resource poor farmers), and respond to other inarticulated demands for technology.

Table 1. CGIAR Members, Contributions, and International Scientists, 1972-95

YEAR	Members of CGIAR[a]	Support to Agreed Research Agenda (Million $)[b,c]	Support to Non-Research Agenda (Million $)	World Bank Contributions (Million $)	Expenditure By Activity (Mil. $)[d]					Number of Scientists (IRS)[e]
					IP	PE	BD	PO	SN	
1972	16	20.7	3.1	1.3						
1973	18	25.0	3.5	2.8						
1974	20	34.5	4.5	2.4						
1975	22 (1)	47.5 (0.6)	6.0	3.2						
1976	25 (2)	62.9 (2.6)	8.0	6.5						
1977	27 (2)	77.2 (2.6)	9.5	7.9						
1978	27 (2)	85.0 (1.8)	10.7	8.7						
1979	27 (2)	99.5 (0.8)	16.2	10.2						
1980	30 (4)	119.6 (2.6)	18.7	12.0						
1981	32 (5)	130.9 (3.1)	20.2	14.6					20.3	
1982	32 (5)	143.8 (2.2)	26.9	16.3					21.8	
1983	34 (5)	164.7 (2.0)	23.7	19.0					25.8	
1984	36 (7)	173.2 (4.5)	29.9	24.3					26.2	775
1985	36 (7)	170.1 (2.4)	41.2	28.1					27.4	841
1986	38 (7)	192.2 (1.6)	43.4	28.4						835
1987	38 (7)	201.6 (1.3)	41.8	30.0						889
1988	39 (7)	211.5 (1.2)	50.6	30.0	79.77			4.07	37.97	925
1989	39 (7)	224.5 (1.0)	47.1	33.3	86.04			4.28	40.46	916
1990	39 (7)	234.9 (1.1)	51.3	34.3	87.01			4.19	42.84	912
1991	42 (9)	232.0 (1.8)	51.6	35.1	85.90			4.82	41.52	882
1992	45 (9)	247.3 (1.8)	71.4	37.6	127.4			25.5	56.1	973
1993	50 (10)	234.7 (2.3)	76.6	40.0	123.5	35.8	14.7	24.8	55.3	957
1994	54 (11)	268.1 (3.1)	57.1	50.0	124.3	40.1	22.6	26.0	51.7	888
1995	56 (15)	269.6 (5.0)	59.0	50.0	134.4	45.3	28.5	25.2	52.6	880

Source: CGIAR Annual and Financial Reports (various issues)

[a,b] Numbers in the parenthesis represent developing countries.
[c] The actual budget of CGIAR is about 5% higher because of center-generated income which is not included in this table.
[d] IP: increasing productivity; PE: protecting environment: BD; biodiversity; PO: policy; and SN: strengthening NARS.
[e] IRS is Internationally recruited staff/scientists

Notes: The agenda funding consists of *unrestricted* and *restricted* contributions. Restricted funding is to the core agenda of CGIAR while unrestricted funding is used for other purposes within the research mandate. Non-agenda funding, on the other hand, is for research outside the CGIAR mandate (e.g. basic research). The break-up of expenditure according to research activities is available only for last three years. Since the classification has changed, systematic accounting of such expenditures is not possible.

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