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AGRICULTURAL SCIENCE AND TECHNOLOGY POLICY FOR GROWTH AND POVERTY REDUCTION

Steven Were Omamo and Anwar Naseem

2033 K Street, NW, Washington, DC 20006-1002 USA • Tel.: +1-202-862-5600 • Fax: +1-202-467-4439 • ifpri@cgiar.org
www.ifpri.org

Abstract

This paper argues that the largely unrealized potential of agricultural science and technology (S&T) in promoting growth and poverty reduction in developing countries results from deeply rooted incompatibility among policy environments, institutional arrangements, and micro conditions and behavior in agricultural research and development (R&D). Achieving growth and poverty reduction based on greater agricultural productivity therefore means achieving greater compatibility among these three dimensions of agricultural innovation systems. Research is sorely needed to build understanding of (1) the "big picture" influencing agricultural S&T policy design and implementation in developing countries, (2) strategies for sustainable funding and delivery of agricultural R&D, (3) priorities for and impacts of emerging and prospective agricultural technologies, and (4) the role of science in food and agricultural policy processes. Agricultural S&T policy analysis as presented here extends beyond the current boundaries of agricultural economics into such disciplines as public finance, public administration, political science, history, sociology, and psychology. The economics of science and innovation in industry has embraced some of these disciplines and benefited greatly from having done so, as has industrial policy in the developed world. The fundamental horizontality of agricultural development policy and the long reach of agricultural S&T policy suggest similarly high returns were agricultural economics to do the same for science and innovation in agriculture.

Key words: agriculture, science, technology, policy, institutions

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1. Introduction

"There is no such thing as science policy in the abstract." – Maurice Goldsmith, 1988[1]

This paper considers the central problem facing agricultural and overall economic policymakers in many countries around the world, namely, how to promote self-sustaining processes of growth and poverty reduction fueled by technological advances in agricultural production and trade. This problem has long been recognized in the literature (Hunter 1973; Jones 1965; Johnston and Mellor 1961; Timmer, Pearson, and Falcon 1983; Tomich, Kilby, and Johnston 1995). The evidence base is substantial and compelling; it supports the notion that agricultural productivity growth is crucial to agricultural sector growth, which, in turn, is crucial to broader economic growth and poverty reduction (Evenson and Gollen 2001; Timmer 1997; World Bank 2001). The world over, policy establishments have incorporated this idea into key policy statements. National development strategies typically proclaim agriculture's importance in national economies, along with ambitious targets for agricultural growth (Ngigi 2004). Yet in many cases, agriculture is accorded low priority in public resource allocations. And left to themselves, agricultural sectors in many parts of the world are registering growth rates insufficient to keep pace with population growth (ASARECA/IFPRI forthcoming; IAC 2004; World Bank 2002).

Concern over sluggish agricultural growth has led recently to a number of high-profile initiatives and commitments seeking to reverse these trends. In most cases, agricultural science and technology (S&T) are viewed as central to progress. The United Nations Millennium Report describes approaches to applying science, technology, and innovation in order to achieve the Millennium Development Goals, with applications in agriculture viewed as crucial and warranting special attention (UN 2004). The World Bank, Food and Agriculture Organization of the United Nations (FAO), World Health

[1] Cited in Garfield 1988.

Organization (WHO), and United Nations Environment Programme (UNEP) recently launched a joint international assessment of the role of agricultural S&T in reducing hunger, improving rural livelihoods, and stimulating economic growth (World Bank/FAO/ WHO/ UNEP 2003). In Africa, the New Partnership for Africa's Development (NEPAD) has launched the Comprehensive Africa Agriculture Development Program, which judges investments in agricultural S&T to be crucial for sustaining agricultural and overall development on the African continent (NEPAD 2004).

Between 1976 and 1992, the World Bank committed more than $5 billion to agricultural research and extension around the world; in the mid-1990s, annual support levels totaled more than $400 million (Purcell and Anderson 1997). Investments such as these have yielded high returns and important impacts on poverty in the past (Alston et al. 2000; Fan, Hazell, and Thorat 1999; Fan, Zhang, and Zhang 2001). Further progress is curtailed by weaknesses and deficiencies in agricultural S&T policy regimes that imply institutional arrangements and organizational forms unsuited to development and broad-based diffusion of poverty-reducing innovations (Byerlee and Alex 1998; Purcell and Anderson 1997).

Investments in S&T are known to pay off most strongly for countries and regions with highly integrated technical and economic systems able to diffuse and apply results of new research (Nelson 1993; Rosenberg 1994). Microeconomic conditions in poor areas render agricultural production and trade risky and costly, militating directly against adoption and diffusion of improved technologies (see, for example, Binswanger and McIntire 1987; Binswanger and Rosenzweig 1986; Fafchamps 1992; Omamo 1998a, 1998b). Prospects are therefore dim for adoption of growth-enhancing and poverty-reducing agricultural innovation in these areas. Justification for policy intervention is strong. But what needs to be done, and, more importantly, how?

Tentative answers are emerging. The most promising developments feature a strategic combination of technical improvement with institutional innovation, often aiming to build robustness into technologies through integrated systems—for example, in pest control, soil management, agroforestry, and crop-livestock interactions (Kilimo 2005). Novel "management platforms" that bundle together soil improvement, new crop and livestock varieties, intensified input use, and collective action by farmers are revealing potential for increased incomes, improved sustainability of farming systems, and adaptation to a range of farming systems and agroecologies (see, for example, AHI 2005; ASB 2003; ICIPE 2005; ILRI 1998; NRI 1992; Place, Otsuka, and Scherr 2004; SACRED-AFRICA 2001). But poor areas are marked by highly diversified farming systems, limited market development, poor access to key services (such as credit and financial services), and structural constraints on the spread of information. How to strengthen and cost-effectively scale up and scale out these promising (but management-intensive) systems and platforms in these areas remains unclear (Kilimo 2005).

A key recognition is that different agroecological and market conditions require not only different technologies but also different providers of technology across the public, private, and civil society sectors (Byerlee and Alex 1998). Greater clarity on the roles and capacities of alternative providers,and on the nature of policies and institutions that promote emergence of those roles in given contexts, is crucial.

Several positive and normative questions arise. In which direction is agricultural R&D moving at global, regional, subregional, and national levels, why, and how? Who gains and loses under these dynamics,and how (through which mechanisms of power and influence)? Are these dynamics conducive to development of institutional arrangements and organizational forms that promote pro-poor development and diffusion of agricultural innovations? How do agricultural S&T systems vary across the globe, and why? Which agricultural S&T policies and institutions are most appropriate and effective in given systems, and why? Which kinds of investments in agricultural R&D will have the greatest impact on growth and reduce poverty the most, especially among vulnerable groups like women and children? Which mechanisms of power and influence are required and available to reverse undesirable trends and conditions?

Such questions have been only partially raised and addressed by the agricultural economics profession. Yet such questions go to the core of most of the problems preoccupying many important segments of the profession, especially those concerned with agricultural and overall economic development. This paper seeks to help fill that gap in two ways. First, it proposes a simple but comprehensive conceptual framework for addressing these questions—a framework that has gained considerable currency in other branches of economic analysis but has yet to be widely applied in agricultural economics. Second, the paper sets out four related but distinct priority areas for research within that framework. A central theme in the analysis is the importance, first, of grounding agricultural S&T policy analysis in the realities of institutional arrangements, microconditions, and microbehavior, and, second, of drawing linkages between S&T policy and broader sectoral, national, and international policy environments.

The remainder of the paper is organized as follows. The next section sketches the proposed conceptual framework for agricultural S&T policy analysis, followed by a discussion of four topics that should receive top priority. A brief summary and conclusions round out the analysis

2. Policies, Institutions, and Microbehavior

The comparative efficacy of alternative institutional arrangements varies, on one hand, with the policy (and institutional) environments within which economic activity takes place, and, on the other, with the attributes and behavior of given actors, both individuals and organizations (Davis and North 1971; Williamson 1994). Conditions and changes in policy and institutional environments define (and sometimes shift) the comparative costs of institutions, which, in turn, influence and reflect behavior at the micro level (Figure 1). Understanding institutional arrangements, and ascertaining the scope for welfare-enhancing institutional innovation, means understanding the driving forces behind the larger and smaller phenomena that those institutions condition and express.

Figure 1: Policies, institutions, and microbehavior: A three-level schema

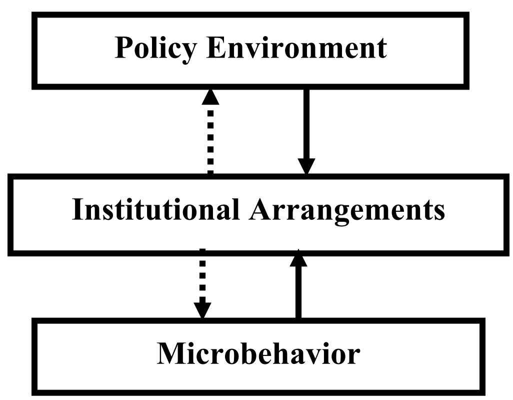
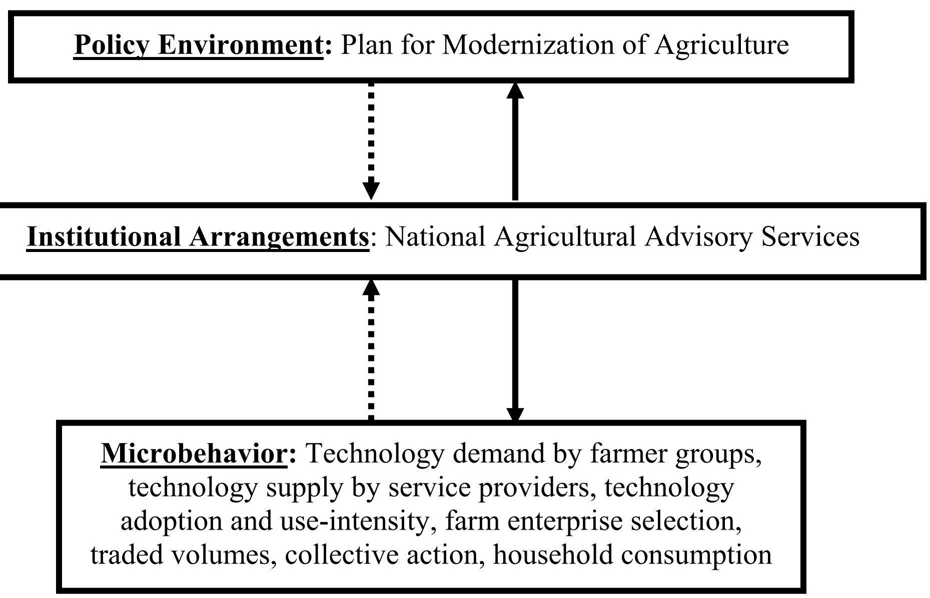


Figure 2 illustrates the Davis-North-Williamson schema with an example from Uganda. The Plan for Modernization of Agriculture is Uganda's framework for eradicating poverty. Its vision is to eradicate poverty by building profitable, competitive, sustainable, and dynamic agricultural and agro-industrial sectors. Its mission is to accomplish its vision by transforming subsistence agriculture into commercial agriculture. It is built on seven pillars (or intervention areas): agricultural advisory services, agricultural research and extension, agricultural marketing and processing, rural finance, agricultural education, natural resource management, and physical supportive infrastructure (Uganda, MAAIF/MFPED 2000). Uganda's National Agricultural Advisory Services is arguably the most important institutional innovation under the PMA. NAADS seeks to increase the efficiency and effectiveness of agricultural extension via far-reaching reforms and innovations in service delivery. The aim is to replace public delivery of services with private delivery in a demand-driven, farmer-led extension system. Farmers are organized into groups responsible for formulating and prioritizing their needs and then contracting and monitoring services provided by private suppliers. In line with broader policies of decentralization, local governments are charged with implementing NAADS activities in their respective districts. The private sector is responsible for delivering advisory services to farmers based on agreed contracts. NGOs assist with farmer mobilization and capacity development; they may also establish commercial arms and participate in service delivery. The policy environment established by the PMA sets the parameters within which NAADS institutions (and specific programs and initiatives therein) function, thereby defining incentives for technology and service delivery by providers and the adoption of technology by farmers.

Figure 2: Policies, institutions, and microbehavior: An example from Uganda



In the Davis-North-Williamson schema, the broad analytical challenge in agricultural S&T policy analysis is therefore to track conditions and changes in policy environments, institutional arrangements, and microbehavior. The ultimate aim is to identify changes in policies and institutions that improve incentives for micro-level decisionmaking. These incentives aim to enhance development, adoption, and diffusion of productivity-increasing technologies. The framework therefore opens up possibilities for building insight not only about *what* needs to be done to promote growth and reduce poverty, but also about *how* it might be done at the macro policy level, at the meso institutional level, and at the micro level.

This framework might be viewed as one way to capture the economic underpinnings of the powerful but often empirically elusive innovation systems. The central idea in the innovation system framework is that the rate of technological change and economic growth depends as much on social and political innovations as on purely technical ones (Freeman 1995). Innovation is viewed as strongly embedded in prevailing social, political, and economic systems, which therefore determine what is learned, where, and by whom (Metcalfe 1995). The search is therefore for practices and policies that promote the innovation process. In agricultural innovation systems, farmers, traders, and a range of organizations are viewed as innovating not in isolation but rather in interaction with one another within the context of institutions that span the public, private, and civil society spheres. Together with the technology employed, institutions determine the costs of production and transaction and thus total costs. Innovation thus begins with individual firms or entrepreneurs but then broadens out to the environment and industry in which they operate; finally, it encompasses national and international systems of regulation, institutions, human capital, and government programs (Niosi et al. 1993). At each level, the question is how processes of learning, searching, and exploring result in new products, new techniques, new forms of organization, and new markets. In this setting, learned routines, embedded in extant practices and livelihood strategies, are likely to be selected over other potentially better ones (Omamo and Lynam 2003). Technical change thus hinges on technical and organizational discontinuities. How can such discontinuities be brought about? How can they be *made to happen*? Such is the challenge for agricultural S&T policy design and implementation. Such is the motivation behind the selection of the four priority areas set out below, which together aim to capture both the "big picture" in agricultural S&T policy and some key details.

3. Comparative Agricultural Science and Technology Systems

A clear-cut definition of agricultural S&T policy is difficult to locate in the literature. Building on a definition of agricultural research policy provided by Omamo, Boyd, and W. Janssen. (2000), an agricultural S&T "policy system" (or simply "system") is defined here as comprising structures and processes for setting priorities, specifying agendas, financing, organizing, delivering, monitoring, evaluating, and assessing impacts of agricultural research, extension, education, and technology and information acquisition and exchange.[2]

Such a definition highlights how little systematic and internationally comparable information is available about the structure, functioning, and performance of agricultural S&T systems around the world.[3] Variation across regions and countries in the potential determinants of system structure and functioning implies diversity in agricultural S&T systems. Such variation is poorly understood. The Davis-North-Williamson framework suggests that institutional arrangements embedded in given agricultural S&T systems condition the behavior of R&D service providers, farmers, traders, and other actors, thereby determining overall system performance.[4] Such relationships and dynamics have yet to be examined in detail. Especially lacking is knowledge about the S&T policies and institutions that provide requisite incentives and coordination for broad-based provision and adoption of productivity-enhancing agricultural innovations.

Table 1 outlines a preliminary framework for categorizing agricultural S&T systems in developing countries. First, second, and third "generations" (or stages) of systems are proposed. In keeping with the three-level schema guiding the analysis, the table presents three categories of potential determinants of S&T system structure and

[2] Ergas (1987) and Rosenberg (1994) use similar definitions for science policy in industry.
[3] The International Food Policy Research Institute's Agricultural Science and Technology Indicators initiative is an important source of information about levels and trends of public R&D investment (ASTI 2005).
[4] See Ergas (1987) for similar arguments for industry.

functioning: those relating to policy environments, institutional arrangements, and micro conditions/behavior. First-generation countries might therefore include most African countries, small countries of Central America and the Caribbean, and less-developed countries in South Asia, Southeast Asia, West Asia, and Eastern Europe. Second-generation countries might comprise mid-size Latin American countries like Bolivia, Chile, Colombia, and Peru, mid-size Asian countries like Pakistan and Thailand, North African countries, and possibly Kenya and Zimbabwe in Sub-Saharan Africa. Third-generation countries might include large countries like Argentina, Brazil, China, India, Mexico, and South Africa.

Further development of this framework is required. However, initial analysis suggests that each factor (potential determinant) likely manifests itself differently depending on a particular system's stage of development. For instance, a first-generation system of a country like Zambia (or Cambodia or Nepal or Nicaragua) likely reflects the relatively small size of the economy, the relatively large share of agriculture in the overall economy, the prominence of diversified subsistence-oriented practices, the relatively large role of the public sector in R&D funding and delivery, the relatively small roles of the private and civil society sectors in R&D, the relatively high dependence on donor funds, the relatively low level of development of the its legal system, and the relatively low level of implementation capacity in the public sector.

Conversely, a third-generation system of a country like Brazil (or Argentina or India) would reflect opposite conditions: for example, the large size of the economy, the relatively small share of agriculture in the overall economy, the relatively low profile of diversified, subsistence-oriented practices, the relatively small role of the public sector in R&D funding and delivery, the relatively large roles of the private and civil society sectors in R&D, the low dependence on donor funds, the relatively high level of development of its legal system, and the relatively high level of implementation capacity in the public sector.

Second-generation systems of countries like Bolivia, Peru, or Thailand would probably have features of both first- and third-generation systems: for example, large segments of agricultural sectors featuring diversified, subsistence-oriented livelihood strategies but also large segments pursuing highly commercialized agriculture and steadily falling public funding, but rapidly rising private financing.

The central policy questions relate to system dynamics. How might a first-generation system develop into a second- or third-generation one? What might cause a second-generation system to revert to a first-generation condition? Which S&T policies and institutions are most appropriate at given stages of system development? One would anticipate that there is more at play than mere system size or capacity. How, then, might a small country with a first-generation S&T system become a small country with a second- or third-generation S&T system—in other words, which combination of policies, institutions, and microconditions matter the most, and why?

Table 1: Potential determinants of agricultural S&T system structure, functioning, and performance

Potential Determinant	**First Generation**	**Second Generation**	**Third Generation**
Policy Environment			
Degree of political openness	Low	Moderate	High
Degree of economic openness	Low	Moderate	High
Gender equality	Low	Moderate	High
Agriculture's share of economy	Large	Moderate	Small
Size of economy	Small	Medium	Large
Donor role	High	Moderate	Low
Institutional Arrangements			
Public involvement in agricultural R&D	High in funding, high in delivery	High in funding, low in delivery	Moderate in funding, low in delivery
Private sector involvement in agricultural R&D	Low	Low-moderate	Moderate-high

Table 1: continued

Potential Determinant	First Generation	Second Generation	Third Generation
Institutional Arrangements			
Civil society involvement in agricultural R&D	Low in funding, low in delivery	Low in funding, moderate in delivery	Low in funding, moderate-high in delivery
Level of development of legal and regulatory system	Low	Low-moderate	Moderate-high
Public sector implementation capacity	Low	Moderate	High
Micro-conditions/behavior			
Nature of agriculture	Primarily diversified subsistence-oriented	Diversified subsistence-oriented and commercial segments	Large and prominent commercial sector
Transaction costs in exchange	High	Moderate	Low

An increasingly important issue in agricultural development pertains to transboundary policies. The three-level schema and three-generation framework suggest that scope for successful design and implementation of transboundary S&T policy is defined by the nature of underlying S&T systems. Again, the key questions relate to both structure and dynamics. Can regional S&T policy initiatives fill gaps in national S&T policy regimes? Might regional R&D initiatives be able to confer second-generation attributes to constituent first-generation systems, or third-generation attributes to constituent second-generation systems?

Research in this topic area would therefore seek to (1) ascertain the most important factors determining the structure, functioning, and performance of agricultural S&T policy systems around the world; (2) identify system features that promote or impede agricultural technology development, adoption, and diffusion, and thus prospects for growth and poverty reduction; (3) identify policy reforms and institutional innovations that improve performance of given system types—that is, identify system-specific best practices; and (4) ascertain conditions under which transboundary agricultural S&T policy is feasible, sustainable, and performance-enhancing for given underlying system types.

The following hypotheses are suggested:

1. The structure, functioning, and performance of agricultural S&T systems vary in predictable ways depending on conditions in the wider social, political, and economic systems within which they are ensconced;

2. Countries can be grouped based on the stage of development ("generation") of their agricultural S&T systems;

3. The stage of development of agricultural S&T systems determines the relevance and efficacy of given types ("varieties") of agricultural S&T policies;

4. National agricultural S&T policies must fit with the level of development of national agricultural S&T systems; and

5. Transboundary agricultural S&T policy initiatives can help countries at relatively low levels of system development and performance transcend country-level constraints and achieve outcomes associated with higher-level system development.

Successful examination of these hypotheses would require comparative case studies of selected national and regional agricultural S&T policy system types. Historical and comparative institutional analyses would be needed to uncover how given systems (and their underlying institutions) have emerged over time, why their arrangements are robust and diverse across countries, and why they do or do not change (Aoki 2001). The key is to build understanding about the details and origins of major S&T system institutions and the factors that render them self-enforcing. Assessment of the performance of alternative S&T policy systems hinges on development of performance indicators at each of the three levels of analysis in the Davis-North-Williamson schema. Potential performance indicators include aggregate measures of agricultural growth (or growth in given agricultural subsectors), measures of productivity growth, yield gaps, measures of R&D output, and measures of R&D uptake and utilization. Relevant S&T institutions—such as property rights regimes, market information systems, grades and standards, farmer collective action—also need to be quantified and integrated with such S&T system performance metrics as levels and intensities of technology use, yields, prices and transaction costs, and types and degrees of interaction among key system actors.

Such research would yield sorely needed information about the big picture influencing agricultural S&T policy design and implementation in developing countries across the globe. Such big pictures have proved to be extremely useful for industrial policy design and implementation (see Edquist, Hommen, and Tsipouri 2000; Ergas 1987; Nelson 1993). But within agricultural S&T systems, anecdotal evidence and preliminary analysis suggest three sources of S&T policy failure requiring focused research attention: first, the continued lack of sustainable funding and delivery strategies for agricultural R&D; second, enduring conflict over priorities and impacts of emerging and prospective agricultural technologies; and, third, the limited role and impact of science in food and agricultural policy processes (Omamo et al. 2005).

4. Sustainable Financing and Delivery of Agricultural R&D[5]

Recent research on the interlinked questions of sustainable financing of agricultural R&D and impacts of given investments reveals a field in considerable ferment (Byerlee and Echeverria 2002; Rivera, Zijp, and Alex 2000; Sulaiman, Hall, and Suresh 2005). Public and private roles in funding and organizing agricultural R&D are in flux, with the former declining and the latter increasing in some countries and regions. The arguments for public financing of R&D are well known—nonexcludability, nonrivalry, low purchasing power among key clients, economies of scale and scope, and low risk, compared with market-based provision and delivery. But these attributes of agricultural R&D derive in part from broader policy environments and institutional

[5] R&D is taken here to cover both research and extension.

arrangements; these attributes are potentially as dynamic as are policy environments and arrangements.

New actors are emerging alongside multiple purposes and complementary roles of public and private sector funding. As new knowledge, products, and processes are developed by the private sector (where intellectual property rights can be appropriated), the domain of public-good R&D becomes more dynamic, shrinking in some areas, expanding in others. The extent to which public provision and delivery of agricultural R&D are more or less appropriate than private provision and delivery is thus an empirical issue. So, too, therefore, are financing arrangements for such provision and delivery.

At issue are efficiency, social justice, and operational feasibility of alternative financing arrangements. Efficiency relates to optimal use of resources—equation of demand and supply at prices that reflect true scarcity values. Social justice relates to equity and thus to distribution of economic surplus as demand and supply are equated. Operational feasibility relates to whether a given scheme is possible given extant microeconomic conditions and the incentives and behavior implied by those conditions.

The theoretical literature on the efficiency and equity implications of alternative arrangements for financing and delivering agricultural R&D is well developed; that on operational feasibility is less so (Rivera 1988, 1996a, 1996b, 1997; Rivera and Cary 1997; Rivera and Gustafson 1991). The empirical literature for most developing countries is shallow on all three fronts. Ongoing reforms of agricultural R&D systems in developing countries are therefore proceeding in the absence of reliable evidence about potential and actual impacts of the alternatives under consideration and experimentation (see, for example, Abt 2001a-e; ATIRI 2005; Uganda, NAADS 2005).

The basic challenge in financing and delivering agricultural R&D derives from the intrinsic dual nature of agricultural innovation, which is highly *clustered* at local levels but also highly *dispersed*, both spatially and institutionally. Technology development and diffusion are therefore highly dependent not only on local context, but also on linkages with wider processes of change and coordination in agricultural sectors. The need for local clustering suggests a role for localized (community-level) collective action. The need for spatial and institutional dispersion points to the need for mechanisms that aggregate over such localized initiatives. Such aggregating mechanisms may be public or private. Fiscal and capacity constraints define the scope for public action; institutional constraints define the limits of private action. Extant legal institutions and intellectual property rights regimes impact importantly on micro-level behavior and meso-level outcomes. Very little is known about such relationships.

More is known about collective action in agricultural R&D. Recent research has demonstrated that successful collective action is most likely when the boundaries for the collective good are small and clearly defined; the costs of exclusion are high; there is significant overlap between the location of the good and the residences of its users; the users have a high demand (up to a limit) for the good; the good is vital for survival; the users know the level of benefit that is sustainable; there are few users; the boundaries of the group are clearly defined; those who benefit from commonly held property are more powerful than those who benefit from private property; there are effective arrangements for dispute settlement; people are concerned about their social status and reputation; rule-breaking is easy to detect and there are clear and biting punishments; and the state is unlikely to undermine locally based authority (Knox and Lilja 2004). Little is known, however, about how particular realizations of these conditions intersect with broader social and economic conditions in defining scope for sustainable financing and delivery of R&D services, particularly in areas populated by resource-poor farmers.

At issue therefore are the comparative efficiency and distributive effects of alternative financing and delivery arrangements for agricultural R&D. Also at issue are the administrative costs of collection and disbursement, the scope for generating significant and sustained sources of funds, and risks of distorting private incentives and patterns of development in unintended and unfavorable ways. Opportunity costs of funds raised and committed in particular ways and associated tradeoffs are also key, along with implications for roles for public, private, and civil society actors.

These considerations are especially relevant at this time. Changes in funding approaches often provide the cutting edge to reforms of R&D systems (Abt 2001a-e; Leibenberg and Kirsten 2005; Mbaye 2005; Ngugi 2005). Two recent trends are especially meaningful and in need of special attention: first, the increasing importance of competitive funding arrangements, and, second, the increasingly important role played by the private sector in financing agricultural R&D, albeit unevenly so.

Competitive Funds

Competitive funds are often proposed as a way of increasing efficiency, effectiveness, relevance, accountability, and transparency of R&D programs (Gill and Carney 1999). But their appropriateness relative to other funding mechanisms is an open question (Echeverria and Elliott 2002; Pray 2002). All organizational forms are flawed (Coase 1964); the issue is how do they stack up against each other in terms of cost, relevance—for a given stage in organizational development—and operational feasibility. What are their inevitable inefficiencies, and how remediable are they in given circumstances? Where operationally feasible alternatives to existing arrangements are identified, will they yield *real* net gains if introduced—as opposed to *hypothetical* net gains from comparison of actual structures and organizations with hypothetical ones (Williamson 1994)? Large disparities between actual and hypothetical gains signal opportunities for welfare-enhancing change. But preoccupation with hypotheticals often leads to operational irrelevance. Real costs must be assessed in relation to real choices. The central issues are how alternative arrangements will actually work in practice, and which assumptions plausibly support prospective net gains within particular institutional contexts. Absent such assumptions, inefficiencies, however large or severe, must be viewed as irremediable.

These considerations are especially meaningful given the wide variation across countries and regions in the structure and dynamics of their agricultural S&T systems. The degree to which experiences with competitive funding arrangements in some parts of the world, such as Latin America, apply in others (e.g., Africa) is therefore unclear, as is the extent to which experiences at national levels apply at regional levels, where competitive funds are also growing in importance. The impacts of competitive funding mechanisms on private incentives and patterns of capacity development have yet to be systematically examined. Competitive funds are popular in donor countries. Their growing importance in developing countries reflects the powerful positions often occupied by donors in S&T policy systems in many of these countries. The political economy of competitive funding of agricultural R&D is thus crucial but still largely unanalyzed.

Research in this area would therefore seek to (1) establish the origins and rationale of competitive funding approaches in given countries, regions, and types of agricultural S&T systems; (2) establish the scope, depth of implementation, and comparative efficiency and distributive effects of these initiatives; (3) identify the major operational strengths and weaknesses of the initiatives and the factors determining those strengths and weaknesses; (4) identify the key tradeoffs associated with these mechanisms—who benefits, who pays, how much, where, and when; and (5) identify policy, institutional, and organizational measures and reforms that strengthen design and implementation of competitive funding mechanisms in given agricultural S&T systems.

The following hypotheses are suggested:

1. Competitive funds can spur cycles of more relevant, demand-driven, and cost-effective agricultural R&D, and this can in turn lead to increased sustainability of funding—that is, once national governments, donors, and the private sector are convinced that their priorities are indeed being better served through the establishment of these new funding mechanisms, they increase their own support to the funds.

2. The conditions for emergence of such cycles obtain mostly in first- and second-generation S&T systems, rarely in first-generation systems.

3. The rise of competitive funding mechanisms in the first-generation systems of many developing countries is driven more by subjective donor interests than by objective assessments of how these mechanisms address specific system failures.

4. Most agricultural S&T systems require a multiplicity of funding mechanisms; competitive funds should only rarely feature prominently in funding portfolios.

A unified methodology for testing these hypotheses has yet to be developed. As noted by Williamson (1994), such a framework must permit symmetrical exposure of the strengths and weaknesses of all feasible organizational forms, describing and costing out the mechanisms of any proposed reorganization. The opportunity costs of implementing competitive funding schemes in given circumstances must therefore be central to the methodology. Qualitative and quantitative indicators of performance must relate to the stated objectives of the schemes (for example, enhancing productivity, promoting innovation, increasing quality, ensuring client orientation, enhancing equity across regions or target groups, strengthening institutions, encouraging collaboration), and also to generic performance criteria such as additionality, accountability, administrative cost, flexibility (responsiveness to research needs), sustainability, and acceptability.

Private Investment

Private investments in agricultural R&D already surpass those from public sources in many developed countries and are rising quickly in some developing countries (Byerlee and Fischer 2000; Pray and Umali-Deininger 1998). The increasing use and internationalization of intellectual property rights (IPR) to protect innovations, privatization of input industries, and general commercialization of agriculture point to further improvements of investment climates facing private R&D enterprises. However, there is precious little empirical evidence on the impact of such IPR mechanisms as patents, plant variety rights, and farmers' rights on food and agriculture in developing countries.

Market failures in harnessing privately funded and privately convened R&D for the benefit of poor producers and consumers in developing countries have been identified (Byerlee and Fischer 2000). Very few applications with direct benefits to poor consumers or to resource-poor farmers in developing countries have been introduced (AATF 2005).

Defining, enforcing, and exchanging property rights over R&D outputs are not trivial exercises. Recent (largely anecdotal) evidence suggests that private property solutions to the underlying coordination problem are not working well. New forms of collaboration are required. There has been little detailed analysis of the incentives and mechanisms required to effect such partnerships. Public organizations' bargaining chips in the required new forms of collaboration are unclear—in other words, how can they best assert ownership and ensure that the needs of the poor are met? Private actors' incentives to participate are also unclear. Scope for segmenting markets that complement private sector interests, or for designing systems of private ownership of R&D results that justify private investment in pro-poor technologies, has yet to be examined in detail. A key question is whether there is a viable middle ground between pure private ownership and the unprotected public domain (Creative Commons 2005; Science Commons 2005).

Incentives for investment in agricultural R&D are defined by institutional arrangements in given agricultural S&T systems. As noted above, such systems comprise structures and processes for setting priorities, specifying agendas, financing, organizing, delivering, monitoring, evaluating, and assessing impacts of agricultural R&D. Institutional arrangements embedded in given agricultural S&T policy systems condition the behavior of R&D service providers. Variation across regions and countries in the potential determinants of system structure and functioning implies diversity in agricultural S&T systems, and thus variation in the impacts and returns to R&D investments. Such variation is poorly understood, especially for private investment.

Strategies and capacities for managing intellectual property in ways that not only protect the rights of technology developers but also promote technology transfer and, more importantly, pro-poor agricultural technology development and diffusion within developing countries are lacking. The up-front costs of obtaining IPR protection and building national competence are known (Blakeney, Cohen, and Crespi 1999). Harder to predict are the size and distribution of benefits from such investments. Private incentives for R&D on crops and the amount of plant variety protection sought increases with the value of the crop (Butler 1996). Expected benefits from IPR protection can therefore be expected to be low for farming systems dominated by the low-value crops cultivated by most poor households, pointing to a role for public policy in catalyzing and sustaining pro-poor private investment in agricultural R&D.

Research in this topic area would therefore seek to (1) quantify the depth and directions of private investments in agricultural R&D in different types of S&T systems; (2) identify factors influencing private sector investment in agricultural R&D, focusing on the roles and impacts of alternative intellectual property rights mechanisms and systems; and (3) identify policy reforms and institutional innovations that improve incentives for pro-poor private investment in agricultural R&D— best practices in different S&T system types.

The following hypotheses are suggested:

1. Privately funded agricultural R&D that benefits poor producers and consumers in developing countries is hampered by market failures linked to absent or inadequate IPR mechanisms;

2. Expected private net benefits from IPR protection are negative in farming systems dominated by the low-value commodities cultivated by most poor households but expected social net benefits are positive;

3. Static (short-term) costs of IPR protection result in transfers of income away from poor regions, countries, and households, but the greater incentives to innovate due to

IPR protection imply larger dynamic (long-term) benefits for such regions, countries, and households; and

4. Alternative IPR mechanisms differ significantly in their efficiency and distributional impacts and thus in their applicability across S&T systems at different levels of development.

Testing these hypotheses would require expansion of databases such as the Agricultural Science and Technology Indicators (ASTI 2005) to capture more fully trends in levels and compositions of private sector investment in agricultural R&D across the globe. Also required would be characterization of the types of agricultural R&D undertaken by the private sector, the outputs of such research, and incentives and constraints on private investment in countries and regions at different stages of S&T system development. Quantification of costs and benefits associated with design and implementation of alternative IPR systems (such as patents and various forms of plant variety rights and farmers' rights) would be required, focusing on identifying policy options that enhance scope for private investments in areas, commodities, and technologies of importance to the poor.

5. Priorities and Impacts of Emerging and Prospective Food and Agricultural Technologies

Advancements in science continually throw up new technologies. The history of the last two centuries is replete with examples of new and revolutionary technologies. That history teaches that many of these inventions did change the world for the better, but many did not. Most important, a significant number of these technologies turned out to have both benefits and risks that were wholly unanticipated beforehand. In many cases, some benefits and risks were not discerned until long after the technologies were well entrenched, and all along, there were heated arguments for and against them. If there is a lesson from this, it is that only time and a commitment to openness in identifying and debating both benefits and costs bring increased understanding of what given technologies might mean to the world.

Consider modern biotechnology and the enduring controversy and conflict over its use in development of food and agricultural technologies. Consider the potentially staggering costs to humanity of continued disagreement and policy inertia resulting from that conflict. And then consider the very real possibility that conflicts and policy inertia of the kinds raging for biotechnology today may tomorrow flare up for, say, precision technologies or nanotechnology. Who will control access to computers and satellites that underpin precision technologies? Who will drive the pricing processes for knowledge given the high-level software and management tools needed to take advantage of new information generated and utilized by these technologies? Could nanotechnology provide even greater scope for tampering with nature than does most of the biotechnology on offer today? Some commentators and actors view demands for unequivocal answers to such questions as both ridiculous and counter to the spirit of scientific inquiry. Science, they argue, is too uncertain to permit definitive statements about its future path or about how humans will relate to it. Others argue that until there is complete clarity about future paths and implications, science must be kept on a tight leash. Conflicts deepen, and countless problems potentially open to science-based resolution remain unaddressed.

Consider Africa and the recent furor over genetically modified (GM) grain (specifically Bt maize) in food aid. The presence of GM food in the region not only raised political temperatures, it also rendered inordinately more difficult a range of basic tasks and operations in food relief, such as moving grain through ports and across borders. Perceived risks associated with GM food created an entirely new set of transaction costs. How, for instance, in mid-2002, was Malawi to move maize donated by the United States, and thus containing Bt maize, through Tanzania, in the absence of complementary biosafety protocols in Tanzania and Malawi, and in the absence of associated testing machinery? Ad hoc measures had to be hammered out, under extreme pressure, on such seemingly mundane issues as how to load grain into rail cars and trucks with minimal “escape,” how to cover the loaded cars and trucks, and how long to allow the loaded cars and trucks to sit in given positions. The opportunity costs associated with overcoming such logistical hurdles, coupled with southern Africa’s general reticence toward potentially life-saving GM food, elicited intense scrutiny and opprobrium from food donors and relief agencies. Clearly, the content and nature of the debate on how to respond to food crises has been fundamentally and irreversibly altered. So, too, has the debate been altered on how to achieve longer-term agricultural growth and food security through self-sustaining processes of growth fueled by technological advances. To many southern African stakeholders, GM agricultural technologies are bound to come in the wake of GM food. Enduring uncertainties and controversies over the relevance, efficacy, sustainability, and safety of those technologies render such a progression unpalatable.

Conflict over the role of S&T in agricultural and overall economic development overshadows the fact that there is broad agreement in most circles over the need for new technologies to address the causes and consequences of poverty (IAC 2004; IFPRI 2004). Often lacking, however, is a rigorous and transparent strategic perspective to such agreement. Such a perspective is certainly an explicitly stated aim of the agricultural research community (see, for example, Science Council 2005). Up to now, however, most efforts to deepen and institutionalize such considerations have been mostly inward looking and disengaged from wider public debates about the role of science and technology in development—debates that define paths of knowledge generation in food and agricultural sectors in countries, regions, and across the globe.

Research in this topic area would therefore seek to (1) clarify key concepts, facts, and options for action toward consistent institutions and policies governing emerging and prospective food and agricultural technologies; (2) identify the main emerging food and agricultural technologies with high potential for enhancing growth and reducing poverty; (3) ascertain the implications of these technological possibilities for current S&T

policy—for investment and financing, knowledge management, research organization, human capacity development, and infrastructure development; (4) identify factors generating conflict and impeding consensus on key S&T policy issues; and (5) identify policy reforms and institutional innovations that overcome these factors.

The following hypotheses are suggested:

1. Self-interested actors in S&T systems engage in behavior that maximizes individual gain but reduces collective benefits, thereby erecting tactical and strategic barriers to conflict resolution;
2. Cognition and motivational processes and biases in the ways human beings interpret information, evaluate risks, set priorities, and experience feelings of gain or loss erect psychological barriers to conflict resolution; and
3. Differences in interests and aspirations of disputing parties are often compounded or sharpened by organizational, institutional, and structural factors that range from bureaucratic structures that restrict the free flow of information, to institutional arrangements (intellectual property rights regimes, for example) that reward or punish some parties more than they do others, to political considerations that restrain the freedom of leaders to make necessary compromises, abandon past promises and rhetoric, or risk alienating powerful factions in their constituencies.

Technology assessment and foresight approaches embedded in multiple stakeholder dialogue processes would be appropriate for addressing these hypotheses (Martin 1995). Empirical methods employed would be necessarily eclectic, with selection driven by the technologies and issues under consideration. Possible candidates include economic simulation modeling at different levels of aggregation (household, market, country, region, globe), and qualitative scenario visioning methods. Choices of technique provide important links through which prevailing economic conditions influence future dimensions of technological knowledge (Rosenberg 1994). A detailed understanding of technological change is therefore inseparable from its history. Economic history (or historiography of technical progress) would thus also be relevant.

6. Science in Food and Agricultural Policy Processes

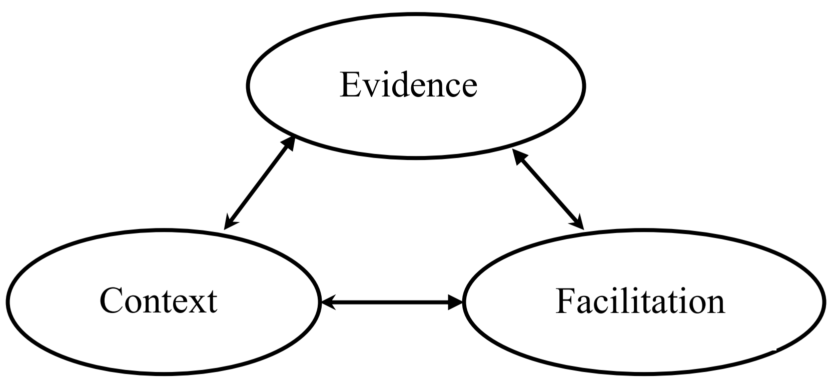
If agricultural researchers are to win and retain the support of policymakers, they must be prepared to engage in policy dialogue. To do this successfully, they must, first, organize themselves to interact with economic and financial policymakers and provide them with relevant information in the forms they require. Second, they must enlist the support of clients and stakeholders. Third, they must demonstrate that research is a sound investment. Fourth, they must express clear strategies and priorities that policymakers can support. Fifth, they must establish management and accountability mechanisms that demonstrate the efficient use of resources and the effective contribution of research to broad social goals. Sixth, they must establish suitable financial strategies with policymakers. Last, they must make better use where possible of the private sector, both as a source of expertise and as a source of funding for research (Elliott 1995). These imperatives are well recognized and clearly underpin increasingly sophisticated and costly "outreach" efforts of research organizations. Yet some fundamental questions about the food and agricultural policy processes targeted in these outreach efforts remain unanswered: Why are some ideas that circulate in policy communities picked up and acted upon, while others are ignored and disappear? Why is it that research-based ideas seem to hold so little sway in those processes? And how can the profile of explicit S&T policy be raised in broader policy debates?

At bottom, the value (and impact) of S&T policy analysis hinges on who gives S&T policy advice, who listens to it, and how it is implemented (Garfield 1988). In an agricultural innovation system context—where innovation is viewed as a process encompassing farmers, traders, industries (sectors), and national systems of regulation, institutions, human capital, and government programs—agricultural S&T policy must be concerned with advice to a multiplicity of decisionmakers. Defining who gives, listens to, and implements S&T policy advice is therefore not straightforward because very little is known about agricultural innovation systems. Less is known about food and agricultural policy processes in those systems. And even less is known about the roles, if any, played by research and researchers within those processes. Anecdotal evidence points to limited use of research output by agricultural policymakers and thus limited policy influence for research. But why this is so remains unclear.

Gaps separating researchers and policymakers in developing countries have long been recognized and lamented. Formal attempts to fill the so-called "research-policy divide" have been made (see, for example, GDN 2001). New research is underway on more effective ways of integrating evidence into policy and on encouraging utilization of evidence in practice, where "evidence" is taken to mean the results of systematic investigation toward increasing the sum of knowledge (Crewe and Young 2002; Nutley, Walter, and Davies 2003). This agenda—which has yet to take root in the food and agriculture sector—has focused on what works in practice, and on what interventions or strategies should be used to meet specified policy goals and identified client needs. It has also addressed broader questions of know-how, know-who, and know-why that hinge more on tacit knowledge than on explicit knowledge. A major focus of attention in this literature is therefore on challenges facing practitioners concerned with policy implementation. In addition to the familiar "research-policy gap," two other gaps are recognized: "research-practice gaps," and "policy-practice gaps." The research-practice gap pertains to lack of appropriate translation of evidence on what works in a particular field into actual practice. Research findings may be underused, overused, or misused. The policy-practice gap refers to poor translation of policy decisions into practice—for example, moving from a policy to privatize state-owned agencies to, say, open franchise bidding as the implementation approach. Research findings may fail to inform policy, guide practice, or both.

Bridging all three kinds of gaps would appear to hinge in the first instance on a fundamental reconceptualization of the role and aim of research in policy processes. In the traditional "rational model," the assumed path followed by research in policy processes is linear: from creation through dissemination to utilization. The rational model pays little attention to implementation or to the practitioners charged with implementation. By recognizing practitioners and placing the search for understanding of their problems on par with examinations of challenges facing researchers and policymakers, the "evidence-based practice" approach implies a shift in focus from a "researcher-as-disseminator" paradigm to a "practitioner-as-learner" paradigm (Nutley, Walter, and Davies 2003). The former paradigm assigns a privileged position to research and researchers; the latter assigns that status to practice and practitioners. Interactions among: first, the nature of available evidence; second, the context within which that evidence is sourced and utilized (or otherwise) in implementation; and, third, the facilitative mechanisms available to various policy stakeholders are decisive (Figure 3).

Figure 3: Evidence, context, and facilitation in policy processes



Research cannot be separated from its social and political context, and especially not from power relations that define facilitative (and convening) capabilities. Processes with thin evidential foundations but deep facilitating powers (such as the donor-driven processes in many African countries) may prevail over research-based ones. Whether a particular piece of research-based evidence is pivotal in a given policy process or not is therefore a purely empirical matter, defined by the conduciveness (or otherwise) of extant contextual infrastructures and available facilitation mechanisms.

Research in this topic area would therefore seek to (1) identify the factors and conditions that influence the role of research in food and agricultural policy processes and (2) ascertain how the role and impact of research in these processes can be enhanced.

The literature identifies eight pathways through which research (science) can enter into policy processes: *dissemination* – presenting and circulating research findings in finished and tailored forms; *education* – increasing knowledge and understanding of research findings; *social influence* – changing norms and values as a route to changing behavior; *collaboration* – improving flows of information and ideas among researchers and potential users by strengthening linkages; *incentives* – encouraging and rewarding activities that enhance research impact or that conform to best practices; *reinforcement* – peer affirmation of impact-enhancing behavior and attitudes; *facilitation* – providing means to support and enable research-based policy and practice; and *multifaceted initiatives* – measures with two or more of the above mechanisms, seeking multiple integrated and mutually reinforcing impacts (Walter, Nutley, and Davies 2003). In theory, the range of choice in potential interventions is therefore wide.. In practice, that range is likely to be quite limited. These eight pathways therefore define a set of testable hypotheses on the role and impact of science in food and agricultural policy processes. Testing these hypotheses would require detailed diagnostic analysis of food and agricultural policy processes in order to shed light on interactions across the three dimensions proposed by the evidence-based practice paradigm: first, the nature of the available evidence (both current and potential); second, the social and political context within which research and policy are practiced and embedded; and, third, the resources, structures, and processes available for facilitating change. Recent research suggests the need for eclecticism in choice of analytical framework for understanding policy processes, with useful insights possibly emerging from a range of models and approaches including institutional rational choice theory, punctuated equilibrium theory, innovation and diffusion models, the advocacy coalition framework, and political resource theory (Sabatier 1999).

7. Summary and Conclusions

This paper has argued that the largely unrealized potential of agricultural S&T in promoting growth and poverty reduction in developing countries can be viewed as resulting from deeply rooted incompatibility among policy environments, institutional arrangements, and microconditions and microbehavior in agricultural R&D. Achieving growth and poverty reduction based on greater agricultural productivity therefore means achieving greater compatibility among these three dimensions of agricultural innovation systems. The paper has identified four priority areas for research in the coming years: comparative assessments of the structure, functioning, and performance of agricultural S&T systems; sustainable financing and delivery of agricultural R&D; conflict resolution and consensus building on priorities and impacts of emerging and prospective technologies; and the role and impact of science in food and agricultural policy processes.

Clearly, agricultural economists could play important roles in responses to these priorities. Many of the underlying issues are familiar to the profession. Yet equally clearly, agricultural S&T policy analysis as presented here extends beyond the current boundaries of agricultural economics into such disciplines as public finance, public administration, political science, history, sociology, and psychology. The economics of science and innovation in industry has embraced some of these disciplines and benefited greatly from having done so, as has industrial policy in the developed world (Dosi 2000; Stoneman 1995; Nelson 1993). The fundamental horizontality of agricultural development policy (Bonnen, Hedley, and Schweikhardt 1997) and the long reach of agricultural S&T policy in agricultural policy (Omamo and Lynam 2003) suggest similarly high returns were agricultural economics to do the same for science and innovation in agriculture.

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