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The Private Sector in Agricultural R&D: Policies and Institutions to Foster its Growth in Developing Countries

Anwar Naseem, Steven Were Omamo, and David J. Spielman

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

New technologies are critical to enhancing agricultural productivity and reducing poverty in many developing countries. While public-sector investment in research has historically driven technological change in agriculture, recent trends suggest that the public sector's role may not be as significant in the future. There is much optimism about the private sector's capacity to deliver new technologies, even though current levels of private investment in research in developing countries remain low. This paper examines the determinants of private investment in agricultural research and development in developing countries, the market and institutional constraints that limit private investment growth, and the incentive mechanisms that can strengthen private investment responses in agricultural R&D—from both the demand and supply sides—particularly in relation to pro-poor growth.

Key words: agricultural research and development, private sector, agricultural productivity

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1. Introduction

The role of science and technology in promoting economic growth and welfare improvement is well established, particularly in the field of agriculture and rural development. New technologies can enhance the quantity and quality of agricultural yields and output, while also improving the sustainable use of natural resources, reducing consumer food prices, connecting rural producers to market opportunities, and stimulating the accumulation of physical and human capital for rural households and individuals. These improvements ultimately translate into higher incomes, greater food consumption, better nutrition, and favorable changes in the allocation of individual and household assets (Meinzen-Dick et al. 2003; Hazell and Haddad 2001). Technologies such as improved crop varieties, human and livestock vaccines, and communications and information technologies have generated impacts through these pathways.

Figure 1 summarizes the relationship between technology and poverty reduction. While technological change has an indirect impact on poverty (through economic growth) and a direct impact (through higher incomes and nutrition), feedback and reinforcement mechanisms are important. As incomes rise and more people come out of poverty, investments in human capital increase, resulting in more capacity for knowledge creation and further innovation. In the same manner, greater overall economic growth enables more resources to be devoted to investment in new technologies.

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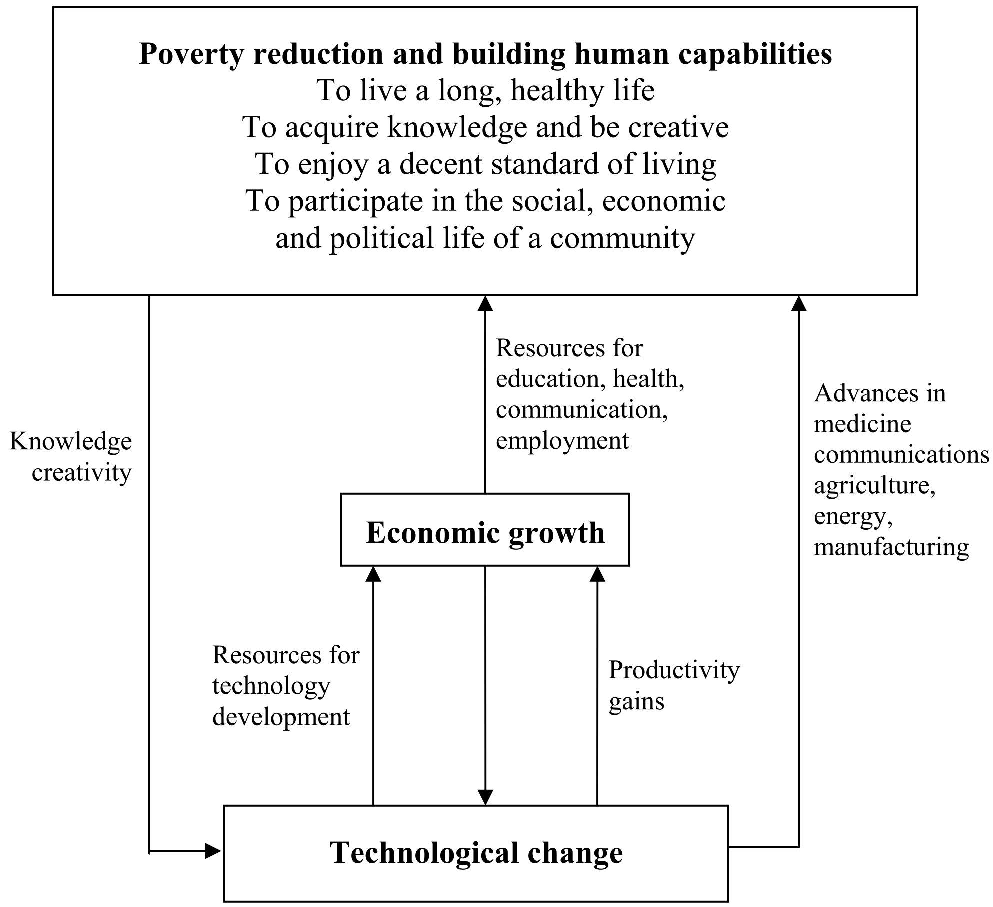
Figure 1: The relationship between technology and poverty reduction



Source: UNDP (2001).

Yet in spite of the impressive body of knowledge on science and technology, and its relationship to incomes and livelihoods, the impact of technological change on poverty reduction has been quite limited in many parts of the developing world. The absolute number of poor people in many countries continues to rise, even though the incidence of poverty may be on the decline. The causes of poverty are obviously complex, and a lack of technology is just one factor: socioeconomic institutions, political economies, organizational behavior, and many other factors are also at play.

In addressing these issues, it is important to recognize that technological change is the result of agents in the public and private sectors investing in research and development (R&D). The level of participation of these two sectors in R&D varies for reasons that are examined later. In the case of agriculture, historically, the public sector has played a central role in developing growth-enhancing technologies that have had a direct impact on the poor in developing countries. The private sector, however, has played a far more limited role. Furthermore, what limited private R&D investment has occurred in developing countries has often focused on a small set of crops, traits, and technologies that respond to the needs of large-scale, capital-intensive farm operations that mirror farming systems in developed countries. Large parts of the developing world host significant numbers of small-scale, resource-poor farmers, landless agrarian laborers, and food-insecure households that have been passed over by the estimated $2 billion in private research investment the private sector has made in the developing world.

Nonetheless, evidence suggests that private R&D investment trends in developing-country agriculture may be changing. First, growth in investments in public-sector research has stagnated in many developing countries, with noticeable declines in Sub-Saharan Africa. Bureaucratic and organizational inefficiencies have exacerbated the situation, resulting in a decline in the quantity and quality of public-sector R&D outputs. At the same time, the international agricultural research system—a critical input to public sector R&D at the national level—has experienced its own funding constraints and strategic challenges (Pray and Umali-Deninger 1998; Pardey and Beintema 2001; World Bank 2004).

Second, the strengthening of intellectual property rights (IPR) regimes in some developing countries, particularly with respect to the protection of biological innovations, has improved the ability of firms to appropriate the returns on their R&D investments. With the implementation of Trade-Related Intellectual Property Rights (TRIPS), more and more developing countries are becoming attractive opportunities for private investment in the agricultural sector.

Third, new and emerging innovations, such as biotechnology, information technology, and communications technology, are largely developed and owned by the private sector. Access and adoption of these innovations rests firmly on the capacity of developing countries to stimulate private investment, particularly in R&D.

Finally, the commercialization of smallholder agriculture, combined with the widespread privatization of formerly state-owned input supply firms, has opened up new market opportunities for private-sector R&D firms in the agricultural sector (Pray and Umali-Deninger 1998).

In light of these changing realities, many developing-country policymakers are looking to the private sector to “fill the gap” and deliver pro-poor technologies (Pray and Umali-Deninger 1998). It would, however, be unrealistic to expect that the gap will be filled by the private sector. A host of market, organizational, and policy factors must be in place before the private sector can supply technologies that are simultaneously productivity-enhancing and poverty-reducing. This paper seeks to identify these factors and argues that the conditions needed to stimulate pro-poor agricultural R&D by the private sector are largely absent in many developing countries. The standard explanation for the lack of private-sector participation (small markets, low appropriability of R&D, high costs, and risks) are relevant but do not capture the complexities of the R&D market and the disincentives created by high transaction costs, poor institutions, and weak R&D policies. The paper examines various options that may foster private-sector participation in R&D, paying particular attention to the role of economic incentives. The paper goes on to propose an agenda for further research, capacity strengthening, and policy communication on these options.

The remainder of the paper is structured as follows. Section two provides an overview of the state of private investment in agricultural R&D and emerging trends in developing countries. Section three provides the conceptual framework that explores the determinants of private investment in agricultural R&D and the causes of limited participation in developing countries. The framework contributes to the identification of the incentives necessary to increase private investment in agricultural R&D. Section four discusses push and pull mechanisms that can be employed to encourage private R&D investment. An agenda for further research on pro-poor private R&D is outline in Section five, followed by concluding remarks in Section six.

2. Private Agricultural Research: Size and Structure

A Brief History

Private-sector investment in agricultural R&D in developing countries has a rich history, beginning in colonial agricultural production systems during the early 19th century, where private farming operations invested in research for export crops (Pray, Oehmke, and Naseem 2005). Examples include research on tea, coffee, rubber and oil for plantation farming in Asia; wheat and maize for *haciendas* in Latin America; and bananas for multinational corporate operations in Central America (Pray, Oehmke, and Naseem 2005). Private R&D increased considerably in the post–World War II period, especially with new breakthroughs in chemical and mechanical engineering and the entry of input supply firms specializing in these fields. During this period, the research focus shifted from export cash crops to grains and other subsistence crops that were critical to ensuring food security in many newly independent nations. Private firms entered into a wider array of research in the areas of fertilizers, pesticides, farm machinery, and, to a lesser extent, plant varieties. Though the bulk of this research was conducted by firms based in developed countries, some private R&D investments were made in developing countries to transfer and adapt these technologies to local conditions (Pray, Oehmke, and Naseem 2005).

Most private-sector investment in agricultural R&D is distributed across six subsectors: (a) basic plant biological research; (b) plant breeding and the production of seed and planting materials; (c) agrochemicals, including chemicals for plant protection, fertilizers, and biotechnological applications; (d) processing, storage, and transport of food; (e) animal and livestock improvement; and (f) agricultural equipment and machinery. About one-third of private-sector investment in agricultural R&D globally is directed toward agricultural chemicals, most significantly pesticides (Pray and Fuglie 2001). Food processing, storage, and transport also provide a significant portion of private-sector investment in agricultural R&D (Pardey and Beintema 2001).

This paper's primary focus is the first two of theses subsectors—basic plant biology research, and plant breeding and the production of seed and planting materials. Arguably, advances in these subsectors can result in significant productivity gains that also have the potential to enhance the health and well-being of the rural poor, who rely on food crops as their primary source of nutrition. Furthermore, with the exception of improvements in the livestock subsector, technologies generated in the other subsectors are designed to supplement or enhance the essential reproductive powers of the seed. With the advent of biotechnology, plant breeding and new crop development have become highly knowledge-intensive, and thus give rise to issues of public versus private goods, the appropriability of a given technology, and other key issues in R&D discussed later.

Data Problems

Before discussing the role of private-sector investment in agricultural R&D in developing countries, it is important to note that the study of this issue is severely constrained by a scarcity of data. This is due to several factors. First, unlike many developed countries, private firms in many developing countries do not regularly report their R&D expenditures to public authorities for statistical, taxation, or other purposes. And even where firms do report their R&D expenditures, very few (in either developing or developed countries) offer detailed breakdowns by crop, technology, region, and so on, as the information is often critical to maintaining an edge over competitors. Second, in many developing countries new technologies often result from the effort of small firms that do not separate research from other development investments. Finally, given the central role of public R&D in developing countries, few data collection initiatives have made focused efforts to collect data from the private sector.[1]

Global Estimates

Globally, the private sector spent an estimated US$869 million in 2000 on agricultural R&D in developing countries (Table 1).[2] When compared with the amount spent by the public and private sectors in industrialized countries, and to the amount spent by the public sector in developing countries, the private sector is clearly a small player in developing-country agricultural R&D. Moreover, of the total amount spent on agricultural R&D globally, private-sector spending in developing countries accounts for only 2 percent (Figure 2).

Table 1: Public- and private-sector expenditure on agricultural research, c. 2000

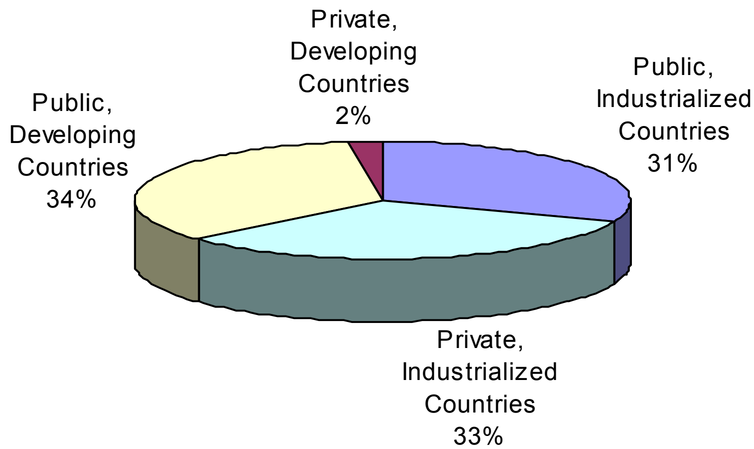
	Expenditure (million 2000 U.S. PPP[a] dollars)			Share of total expenditure (percent)	
Region	**Public**	**Private**	**Total**	**Public**	**Private**
Developing world	12,819	869	13,688	93.7	6.3
Industrialized world	10,191	12,577	22,767	44.8	55.2
Total	23,010	13,446	36,456	63.1	36.9

Source: CGIAR Science Council 2005.
a. PPP indicates purchasing power parity.

[1] Given the time, effort, and cost needed to obtain private-sector data, some published estimates of private R&D expenditures are set at a certain percentage of total agricultural GDP. Other data sources on R&D expenditure (FAO, OECD, World Bank) entirely overlook private investment in agricultural R&D in developing countries.

[2] Other estimates have put this figure as high as $2 billion (see James 1997), where it was assumed that a certain share of private agricultural input sales are devoted to R&D.

Figure 2: Global agricultural R&D spending, c. 1995



Source: Pardey and Beintema (2001).

Country Estimates

For the few developing countries for which estimates of R&D expenditures by private firms are available, most are either middle-income countries (for example, Thailand, Malaysia, and Chile) or large countries with a significant agricultural base (such as, India and China). For these countries, private-sector participation varies considerably (Table 2), but—in all cases—public-sector R&D expenditures exceed those of the private sector; in 2000, for example, private–public expenditure ratios ranged from .01 (for Ethiopia) to 0.5 (for Colombia).

Table 2: Public and private agricultural R&D expenditure in developing countries

Region/country	Year	Public	Private	Private R&D as share of Agricultural GDP	Private/public
Asia[a]					
China	1995	485	16.0	0.011	0.03
India	1995	348	56.0	0.062	0.16
Indonesia	1995	81	6.0	0.017	0.07
Malaysia	1995	64	17.0	0.148	0.27
Pakistan	1995		6.0	0.042	
Philippines	1995	38	11.0	0.069	0.29
Thailand	1995	127	17.0	0.107	0.13
Latin America and the Caribbean					
Belize	1996		0.6	0.618	
Brazil	1996	522	24.0	0.051	0.05
Chile	1996	63			
Columbia	1991	62	32.3	0.002	0.52
Dominican	1993		1.3	0.001	
Ecuador	1991				
Jamaica	1989				
Mexico	1996	155	15.7	0.108	0.10
Africa					
Ethiopia	1998	9.8	0.1	0.003	0.01
Kenya	2000	15.3	0.5	0.044	0.03
South Africa	2000	96.6	4.2	0.158	0.04

Sources: Data for Asia, with the exception of Pakistan, are from Pray and Fuglie (2001); remaining data are from ASTI (2005), with the exception of private-sector data for Colombia and Ecuador, which are from Falconi (1994).
[a.] Data for Asia are in million 1995 dollars.

Commodities

Private R&D tends to focus on a limited number of commodities with particular traits. In Asia, for instance, private R&D is concentrated in cash crops, such as oilpalm, rubber, tea, vegetables, and horticulture; hybrids of rice, sorghum, millet, and maize; and livestock hybrids, such as poultry (Pray and Fuglie 2001; Gerpacio 2003; Tripp and Pal 2001; Morris 1998; Morris, Singh, and Pal 1998).[3] Likewise, private R&D in Latin America tends to focus on hybrid maize. In fact, Morris (2002) reports that private-sector investment in maize research is approximately twice that of the public sector in both Asia

[3] Private investment in hybrid poultry is so prevalent that Narrod and Fuglie (2000) find that 99 percent of Brazilian poultry, 81 percent of Thai poultry, 70 percent of Philippine poultry and 62 percent of Indian poultry are derived from breeds developed by just seven private firms based in developed countries.

and Latin America. Private research on bananas has also been a main focus for firms in Central America and the Caribbean. For Africa, where relatively little private R&D is conducted, the focus has been on export commodities such as tea and coffee, for example in Kenya (Ndii and Byerlee 2005).

Technologies

It is no surprise that private investment in agricultural R&D tends to focus on export crops, for which returns on investment from international markets are an incentive to invest, or on hybrid crops, for which the loss of vigor over successive generations compels farmers to repurchase seed (or, in the case of poultry, chicks). It is also no surprise that private investment in agricultural R&D tends to focus on technologies that are either capital-intensive, labor-saving, or both, since labor is either relatively less abundant in many large-scale farming operations in developed countries or a more difficult production factor to manage due to the potential difficulty in enforcing contracts with agricultural workers in both developing and developed countries.

A useful illustration of this research focus can be found in the emerging field of agricultural biotechnology (agbiotech), where private-sector investment overshadows that of the public sector.[4] With the exception of China, most of the genetically modified (GM) crops cultivated in developing countries were developed by a handful of private, multinational firms based in developed countries. Examples include the herbicide-tolerant soybeans varieties grown in Argentina and insect-resistant cotton grown in Mexico and South Africa. The first GM crop varieties cultivated in developing countries were products directly transferred from developed countries: only later did firms begin adapting the technology into local varieties more suited to the specific agroclimatic conditions of developing countries (Pray, Oehmke, and Naseem 2005).

[4] The overall trend, however, does not reveal the considerable variation in commodity-specific agbiotech research. Public-sector investments in low-value or low-return crops like cassava and millet are significant and larger than the private sector.

A useful indicator of the level and growth of private R&D in agbiotech is the number of field trials approved by government inspection agencies and conducted by private firms (Table 3). In both developed and developing countries, the majority of the field trials are done by multinational firms, which are clearly the leaders in the development of this technology.

Table 3: Distribution of field trials on genetically modified crops in developed and developing countries, 1987–2000

Sector/region	Developed countries (percent)	Developing countries (percent)
Public sector	8	16
Universities	4	12
Multinational firms	70	61
Other private firms	10	8
Unidentified	8	11
Total	100	100

Source: Pray, Courtmanche, and Govindasamy (2002).

Organizational Structure

Underlying the agricultural R&D sector is an organizational structure that has evolved rapidly in recent years. Foreign firms play a key role in conducting agricultural R&D and supplying new technologies to developing countries. In Asia, in the mid-1990s for instance, private research by foreign firms based in the United States and Europe accounted for an average of 45 percent of all private research, ranging from 100 percent in China to just 10 percent in Malaysia (Pray and Fuglie 2001). Given this, it is worth examining the structure of the agricultural R&D sector in developed countries and, in particular, trends toward industry consolidation and vertical integration.

Industry consolidation in the agricultural R&D sector began in the 1990s, as large private firms recognized the potential research synergies that could be realized by integrating biotechnology research in human, animal, and plant biology, chemistry, medicine, and agriculture (King 2001; Brennan, Pray, and Courtmanche 2000). As a result, the agricultural R&D industry has become one of the most concentrated sectors in the world economy (Oehmke 1999). In the United States, the four-firm concentration ratio in the U.S. cotton seed market reached 87 percent by 1998, while the ratio reached 67 percent in the corn market and 49 percent in the soybean market (King 2001; Hayenga and Kalaitzandonakes 1999). Internationally, sales of agbiotech products are dominated by Monsanto Company, accounting for 88 percent of the world market (Fulton and Giannakas 2001).[5]

The increased concentration of agricultural R&D in developed countries has implications for R&D in developing countries. With greater concentration, a small number of firms now control key platform technologies that are necessary for downstream and applied research. Given that many of technologies are proprietary, access will require that developing countries institute mechanisms for technology transfer, either directly through foreign direct investment or indirectly through partnerships. Concentration will also require government anti-trust authorities to carefully weigh the dynamic efficiency gains of new innovations against the static losses from monopoly pricing. In many instances, it will require the creation of new institutions and policies that recognize the emerging role of the private sector in delivering much needed pro-poor technologies suited for developing countries.

3. Conceptual Framework

This section begins by examining the decision problem faced by a profit-maximizing firm seeking to recoup its R&D investment by appropriating the rents from innovation. The problem is illustrated using a microeconomic model of profit-maximizing firm behavior and the social welfare outcomes of a change in productivity resulting from the application of research. The model is then extended to examine the

[5] Note, however, that there is some evidence that the consolidation process has reversed itself in recent years (King 2001). Some of the major multinational life-science firms have divested their agricultural technology divisions, reducing operational size and financing, or sold the divisions outright.

institutional setting within which R&D occurs and within which R&D markets function, both in a theoretical sense and in the context of developing countries. The model provides the context for the study of market failure in R&D—namely the underprovision of new research. The model also provides a basis for discussion of alternative policy interventions, discussed later in Section 4.

A Model of R&D Private-Sector Behavior

A study of private-sector R&D incentives must account for at least one fundamental concept: the ability of agents to appropriate rents accruing from their innovations. As a starting point, consider a model that illustrates how private investment in agricultural R&D is positively associated with appropriability over rents from innovation and market size, and negatively associated with research costs. A game theoretic approach is used to account for the fact that firms conduct R&D not only to increase future profits over their current profits, but also to introduce new technologies that give them a strategic edge over their competitors.

Following the patent race models of Loury (1979), Lee and Wilde (1980), and Reinganum (1984), we consider a one-shot, noncooperative game between two profit-maximizing private firms (*1, 2)*, where the firms invest in R&D with the aim of innovating. The firm that innovates first is awarded an exogenously determined prize (P). The probability of success by firm i is a function of its R&D effort x_i. Denoting w as the cost of conducting research, then wx_i is the flow cost that firm i pays until one firm succeeds. The payoff function of the private firm is specified as the present value of expected profits, net of R&D costs:

$$V_1 = \int_0^{\infty} \exp\{-(\mu h[x_1] + \mu h[x_2] + r)t\}\left[\frac{P}{r}\left(\alpha\mu h[x_1] + (1-\alpha)\mu h[x_2]\right) - wx_1\right]dt \qquad (1a)$$

$$= \frac{(P/r)\left(\alpha\mu h[x_1] + (1-\alpha)\mu h[x_2]\right) - wx_1}{\mu h[x_1] + \mu h[x_2] + r}, \qquad (1b)$$

where r is the discount rate, $h[x_i]$ is the hazard function or the instantaneous probability of innovating, and α is the appropriability parameter that lies on the closed interval [0.5,1] (Reinganum 1989). The hazard function is twice differentiable, strictly increasing, and satisfies the following:

1. $h[0] = 0 = \lim_{x \to \infty} h'[x]$,
2. $h'[x_i] > 0$, and
3. $h''[x_i] < 0$.

The interpretation of the appropriability parameter is as follows. Most R&D race models assume that the returns to R&D for the winning firm is the value of the prize (P), with the losing firm getting nothing (winner take all assumption).[6] However, if we assume that the winning firm is unable to appropriate all of the returns to its research, then it is possible to assume that the losing firm may benefit as well, especially if imitation is costless. The assumption that research is imperfectly appropriable implies that the returns to research may have to be shared at the conclusion of the race. The more appropriable the winning firm's prize, say due to stronger IPR enforcement, the lower the opportunity for the losing firm to copy the winning firm's innovation and reap benefits.

At one extreme, the winning firm's innovation is perfectly appropriable ($\alpha = 1$), resulting in the presence of strong IPR or technology (or both), which eases appropriability. At the other extreme, appropriability is extremely difficult ($\alpha = 0.5$), in which case the winning firm must "share" the value of the prize because it is unable to hold a monopoly position on its innovation. The parameter β ($0 \le \beta \le 1$) is the fraction of the future value of the prize that each firm currently receives, such that βP is the value of current profits. If firms are to conduct research, a situation must occur whereby $\alpha > \beta$.

[6] The notion of a "prize" here should not be taken literally or be limited to a monetary award. It could also imply patent rights giving the winner monopoly over a certain market. The bigger the market, the bigger will be the monopoly rent and the value of the prize.

For the sake of simplicity, we will assume that β is the same for both firms. Finally, μ is the productivity of the research process and is related to the technological opportunity available to the firm. The more technological opportunity that is available to the firm, the greater the productivity of the firm's research.

The exponential term consists of the discount factor, e^{-rt}, times the probability that no firm has innovated to time t, $e^{-(h[x_1]+h[x_2])t}$. The numerator in equation (1b) is the expected value at time t of the net benefits from staying in the race from time t to time $t+dt$, conditional on the fact that no firm has yet innovated. These expected net benefits include the time t expected present value of winning, $(P/r)\alpha h[x_1]$, plus the expected present value of losing, $(W/r)(1-\alpha)h[x_2]$, less the certain cost of staying in the race, wx_1. Written this way, if firm *1* wins the race with probability $h[x_1]dt$, it receives a flow of profits, αW.

The two firms, acting noncooperatively and simultaneously, choose the R&D expenditure in order to maximize their respective payoffs. From the first order condition for a maximum, and given the symmetric nature of the game, the following reaction curve results for the each of the firms in the R&D space $(x_1 = x_2 = x)$:

$$(1/r)(2\alpha-1)h[x]h'[x]P+(\alpha-\beta)(Ph'[x])-rw-2wh'[x]+wPh'[x]=0. \qquad (2)$$

The reaction functions defined by Equation (2) are continuous and will have a unique positive Nash equilibrium: $x_1^*[x_2]$ and $x_2^*[x_1]$. The characterization and properties of the Nash equilibrium are well known (for example, Delbono and Denicolo 1991; Naseem 2002). Of interest to us are the comparative static results indicating how private research effort changes with respect to the variables of interest.

Consider the value of the prize, which we assume to be directly related to the size of the market. Implicitly differentiating (2) with respect to *P*, we get

$$\partial x^* / \partial P = (\mu / r) h'[x] \big(r(\alpha - \beta) + (2\alpha - 1)\mu h[x] \big) > 0 . \tag{3}$$

Thus an increase in the value of the prize increases the optimal research effort of each firm. In a similar manner, it can be shown that research effort is increasing in appropriability:

$$\partial x^* / \partial \alpha = (\mu / r) h'[x] P \big(r + 2\mu h[x] \big) > 0 . \tag{4}$$

Research effort is, however, decreasing in *w*, *r*, and β as shown below:

$$\partial x^* / \partial w = -(r + 2\mu h[x] - x\mu h'[x]) < 0 , \tag{5}$$

$$\partial x^* / \partial r = -\Big(w + (1/r^2) P(2\alpha - 1) h[x] h'[x] \Big) < 0 , \tag{6}$$

$$\partial x^* / \partial \beta = -P\mu h'[x] < 0 . \tag{7}$$

Or, with increasing costs of research, an increasing discount rate, and a decreasing differential between current and future profits, firms will reduce their research effort. The result with respect to the efficiency of research is ambiguous and depends in part on the value of the parameters. Implicitly differentiating (2) with respect to μ we obtain

$$\partial x^* / \partial \mu = \overbrace{w(xh'[x] - 2h[x])}^{Term\ 1} + \overbrace{Ph'[x](\alpha - \beta)}^{Term\ 2} + \overbrace{2P(\mu / r)(2\alpha - 1) h[x] h'[x]}^{Term\ 3} , \tag{8}$$

where the first term is unambiguously negative, while the other two terms that follow take on nonnegative values. It follows then that (8) will be positive if

$$w(xh'[x] - 2h[x]) < Ph'[x](\alpha - \beta) + 2P(\mu / r)(2\alpha - 1) h[x] h'[x]$$

and negative if

$$w(xh'[x] - 2h[x]) > Ph'[x](\alpha - \beta) + 2P(\mu / r)(2\alpha - 1) h[x] h'[x] .$$

A case where (8) would be negative is when the innovation is difficult to appropriate ($\alpha \approx 0.5$) and the differential between post- and pre-innovation profits is small ($\alpha - \beta \approx 0$). In such a case, the two positive terms of (8) converge to zero, and the negative term dominates. One interpretation of this result is that if appropriability is difficult, firms will reduce their research efforts despite rising productivity in research, as they would rather have their competitor take advantage of the increased efficiency and then free ride on their innovation.

The comparative static results derived here can also be generalized to the case of many firms (as in Delbono and Denicolo 1991, where the focus is the comparative static of optimal research with respect to the number of firms) or in the presence of a welfare-maximizing public firm (Naseem 2002). The key comparative static result relating to appropriability, market size, and research costs can also be derived using a partial-equilibrium model as in Evenson and Kislev (1975) or Pray and Fuglie (2001). Table 4 provides a summary of these results.

Table 4: Predicted effect of different factors on agricultural research

Parameter	Comparative static	Effects of the parameter
Market/prize size	$\partial x^* / \partial P$	Larger market size increases private R&D
Appropriability	$\partial x^* / \partial \alpha$	Greater appropriability increases private R&D
Technological opportunity	$\partial x^* / \partial \mu$	Ambiguous
Cost of research inputs	$\partial x^* / \partial w$	Lower cost of research inputs increases private R&D
Discount rate	$\partial x^* / \partial r$	Greater discount rate decrease private R&D
Differential between present and future profits	$\partial x^* / \partial \beta$	Greater differential reduces private R&D

Public and Private Goods, Public and Private Actions

The model set forth above—particularly the attributes of the appropriability parameter α—raises institutional issues that relate closely to public and private R&D in developing- country agriculture. The issue is framed in the standard terms of a property rights and market size issue: the low appropriability of intellectual property afforded in developing- country markets, combined with weak market access or purchasing power of small-scale, resource-poor farmers, results in the chronic undersupply of agricultural R&D by the private sector. This necessitates the provision of research as a public good by the public sector.

The key issue revolves around the difference between public (nonrival and nonexcludable) and private (rival and excludable) goods. A research firm is better able to appropriate rents from innovation and recoup its investments in R&D when the output is excludable. But since it is often difficult to exclude other agents from the consumption of research—in essence, knowledge—economic institutions or technologies that guarantee property rights are required to ensure appropriability.

But several recent studies have added the concept of "impure" public goods to the discussion (for example, Dalrymple 2006; Sandler 2003). The main argument is that agricultural research can often be characterized as an impure public good, where the good's rivalry and excludability are limited to some degree by public policies governing appropriability, the ease with which it can be imitated, the context- or industry-specificity of its consumption, the shared nature of its production by public and private researchers, the spatial level at which the good is produced or consumed, or other complicating factors. Thus, characterizing the issue simply in terms of public or private goods is insufficient. Rather, a nuanced understanding of the scope and scale of complex research processes in the private and public sectors is needed.

Yet property rights and the goods-nature of research only partly explain the institutional context within which research is conducted—that is, the factors that govern or condition its production, exchange, and use. Agricultural research in developing countries is paradoxically diffused across localized processes of discovery and adoption that occur across diverse agroclimatic and socioeconomic conditions; it is also potentially accelerated by efforts to bridge a globally disperse body of highly applicable knowledge and technology. For example, the adoption of improved seed by a small-scale farmer represents both a localized process of research and experimentation and the embodiment of knowledge produced across several countries—knowledge made possible through a system that (a) combines science with markets, policies, and other institutions and (b) is dependent on knowledge aggregated from other farmers in other regions.

This linkage between the local and the dispersed necessitates a high degree of coordination, which in turn requires effective collective action aggregated at different spatial and institutional levels. Such aggregating mechanisms may be public or private. Fiscal and organizational constraints define the scope for public action, while institutional constraints define the limits of private action (Omamo and Naseem 2005). The basic organizational challenge is defined by the nature of agriculture in developing countries: how to retain the high degree of local clustering essential to discovery and adoption of agricultural technologies under extreme agroclimatic and socioeconomic diversity, while promoting diffusion of technologies by bridging the global dispersion that defines small-scale agriculture.

This challenge points to a role for "bridging institutions" of various kinds—for instance, those that

- catalyze improved integration of activity along the continuum from basic, to applied, to adaptive research;
- help to convert technically workable innovations into commercially feasible ones;
- support broad-based experimentation with new procedures by helping to transform uncertainty into manageable risk;
- act as "focusing devices" for this experimentation by linking current directions and contents in trial-and-error activities to desired future outcomes; and
- increase amounts of global information at local levels, thus helping to override the overwhelming influence of transport costs in farmer–trader and trader–trader

interactions (that is, in the expected continued absence of major investments in rural infrastructure).

Many developing countries are also caught in what might be characterized as a technology “gap.” In essence, technological change is dependent on the absorptive capacity of agents—their ability to learn, adapt, and change—and their ability to move incrementally to products and activities of greater technical sophistication and institutional complexity. Technology gaps emerge and expand as promising technologies progressively attract greater learning and as impediments to diffusion are progressively overcome by some agents and not others (Arthur 1988; Dosi 1988; Nelson and Winter 1982). Under such conditions of dynamic increasing returns to technology adoption and learning, markets are unable to relate varying future growth efficiencies to current relative profitability signals: market signal are insufficiently specific.

In short, market processes are generally weak in stimulating the emergence of new technologies. Private investment in agricultural R&D thus rests on the identification of institutional arrangements and organizational forms that can support rapid dissemination of information without necessarily compromising behavior that is individually costly but beneficial when reciprocated.

Thus, the public sector must play a central role in the production and exchange of knowledge. First, it must provide forms of economic stabilization that only governments can provide, including stability in patterns of economic signals, such as relative prices and profitabilities. Second, it must provide the basis for an agricultural science and technology “system,” that is, the structures and processes for setting priorities; specifying agendas, financing, organization, delivery, monitoring, and evaluation; and assessing impacts of agricultural research, extension, and education (Omamo and Naseem 2005); Third, it must provide the institutions that catalyze the emergence of organizational forms, learning patterns, and commitment mechanisms that link local and dispersed processes of innovation. Once met, these conditions stimulate private investment in agricultural R&D.

Thus, private-sector investment is agricultural research is significantly determined by the institutional context in which it is produced, exchanged, and used. These factors extend the model set forth above and go a long way to addressing the issue of cross-country variations in the magnitude and growth of private investment in agricultural research.

Empirical Evidence on Private R&D

What is the relative significance of the factors determining private-sector R&D, as suggested by microeconomic theory and institutional economics? Is a firm's decision to invest in R&D influenced more by market size and the cost of doing research or by institutional factors such as stronger IPR, effective contract enforcement, and efficient bureaucracy? While theory suggests that there are many factors behind a firm's decision to invest in R&D, the relative importance of these factors is an empirical issue. Hence, we next consider several studies that examine these determinants in detail, summarizing them in Table 5.

Table 5: Summary of determinants of private sector research and their effects

Determinant	Effect
Market Size	Larger market size will increase private sector research
Appropriability	Greater ability to appropriate rents from innovation will increase private research
Technological opportunity	Greater technological opportunity will increase private research
Costs	Lower costs of input (capital/labor) will increase private research
Quality of institutions	Higher quality of institutions will increase private research
Firm specific characteristics	Greater cash flow, large firm size will result in more investments from private firms (??)

Source: Adapted from Pray and Fuglie (2001).

Market size and structure

The hypothesis that larger market size increases private-sector investment in research is, by and large, supported by empirical evidence. Griliches (1957, 1989), Schmookler (1966), and Scherer (1982a,b) show that inventive activity is significantly determined by the pull of demand, manifested in market size and patent protection. Using panel data from seven European Union countries over a 10-year period, Alfranca and Huffman (2001, 2003) similarly confirm this hypothesis for the specific case of market size and agricultural R&D. More precisely, they find that the size of the agricultural sector has a concave effect on the elasticity of aggregate private R&D expenditures. This nonlinear relationship results from the large fixed costs associated with R&D—as market size increases, the incremental costs of R&D decrease. Case studies of seven Asian countries by Pray and Fuglie (2001) similarly indicate that market size, appropriability, and research costs all have a strong effect on private investment in agricultural R&D. Tests of the market size hypothesis find particular strength in India, where privatization during the 1990s significantly expanded opportunities for private R&D investment (Pray, Ramaswami, and Kelley 2001; Tripp and Pal 2001; Morris, Singh, and Pal 1998); and in the Philippines, where demand growth in domestic and export markets stimulated private investment (Pray and Fuglie 2001).

The structure of the market also determines the level and magnitude of private-sector investment in agricultural R&D. Historically, state-owned seed monopolies and public-sector seed projects financed by the donor community posed significant entry barriers to private agents (World Bank 1996, 1995).

Furthermore, because private R&D often depends on the ability of a private firm to access information, technologies, materials, and capital from foreign sources, the relative openness of a given economy can determine the degree of private-sector investment (Gisselquist and van der Meer 2001). Until the late 1980s, for instance, government regulations in India barred large Indian firms and firms with majority foreign equity from plant breeding and seed production. Import regulations on germplasm further prevented private-sector interests from importing germplasm for plant breeding purposes (OECD 1994).

Appropriability and property rights

While market size and structure are relatively straightforward determinants of private investment in agricultural R&D, the role of institutions that affect appropriability is far more difficult to demonstrate empirically. At the economywide level, using cross-country data on the strength of IPR, technological change, and other country specific characteristics, Kanwar and Evenson (2003) find that IPR has a strong incentive effect on innovation. The case in support of strong IPR regimes in agriculture is articulated by a number of authors, including Caswell, Fuglie, and Klotz (1994), Fuglie et al. (1996), Lele, Lesser, and Horstkotte-Wesseler (2000), and Nottenburg, Pardey, and Wright (2001). Central to these studies is the standard argument that IPR improves incentives to plant breeders, thereby increasing the flow of technological innovations available to farmers, while also allowing breeders to recoup their investments in R&D. This incentive structure resolves the potential problem of chronic underproduction of knowledge when such knowledge is otherwise nonexcludable.

Yet this is only one of the many reasons to pursue improvements in the strength of IPR regimes worldwide. IPR regimes also reduce transaction costs for plant breeders who would otherwise have to incur the costs of asserting property rights over their information through other means, such as exclusion technologies, exclusivity contracts with farmers, monitoring of seed use and cultivation, or similar arrangements.

Butler and Marion (1985) were among the first to comprehensively study the question of whether plant variety protection (PVP) certificates—a form of IPR protection—affect private investment in agricultural R&D in the United States. They conclude that the private-sector stimulus resulting from PVP legislation enacted in 1970 was limited, at best. However, their study was conducted just over 10 years after PVP legislation came into effect in the United States, a period that may have been insufficient to capture the effects of the legislation on private-sector plant breeders. Now that PVP legislation has been in place for at least 20 years in most industrialized countries, Srinivasan and Thirtle (2000) argue that there is sufficient time and space for empirical study of this issue. To wit, Alston and Venner (2000) study the U.S. PVP Act of 1970 and its impact on private-sector investment in wheat breeding. They find that the increased appropriability attributable to the PVP Act resulted in neither an increase in private investment in wheat breeding nor an increase in experimental or commercial wheat yields. At best, they find that an increase in the proportion of varieties cultivated in the United States that were produced by private firms, from 3 percent of all varieties in the 1970s to 30 percent in the 1990s. They argue that PVP certification provided private firms with a mechanism by which to market, differentiate, and assure the quality of their products.

In one of the few studies on plant breeders' rights legislation in developing countries, Pray (1992) finds that PVP-style incentives had a significant and positive affect on private wheat breeding in the Argentina but not in Chile. He concludes that IPR is a necessary, but not sufficient, stimulus to the transfer of agricultural technology and private-sector investment in plant breeding and that enforcement systems are as important as legislation.

In a different study, Pray, Bengali, and Ramaswami (2004) measure the impact of IPR and complementary institutions on biotechnology research. They find that plant breeder's rights and the strength of property rights in general were positively associated with the spread of applied agricultural biotechnology research as measured by the number of biosafety field trials on GM plants. Other positive and significant variables were the size of the countries' seed industry and the amount of commercialization of the agricultural sector and the amount of public biotechnology research in the country

However, legal forms of IPR explain only part of the story: IPR can also be obtained indirectly, for example, by inherent biological characteristics of a technology or by the ability of a firm to maintain the secrecy of the technology. Pray, Ramaswami, and Kelley (2001), for instance, find that the implicit IPR afforded by hybridization of rice and rapeseed has resulted in greater private-sector investment for these particular crops. Gerpacio (2003) presents similar findings for hybrid maize in Asia.

Moreover, firm and industry structure is also closely associated with appropriability. Pray and Fuglie (2001) find that the vertical integration of plantation-based firms in the production, processing, and export of pineapples and bananas allows for substantial appropriation of innovation rents, particularly when compared with smallholder production of crops such as coconut.

Other institutional factors

Moving beyond the issue of IPR, there are a variety of other institutional factors that affect private R&D. Governance plays a key role in stimulating or inhibiting private investment, especially in the presence of information asymmetries between agents.[7] Consider, for example, the market for improved seed. Since the genetic qualities of seed are only discernible through utilization, experience, or reputation, private firms require a reliable means of conveying information about their product to farmers. Reliable information transmission depends on institutions, such as seed certification systems, truth-in-labeling regulations, and consumer protection laws (Tripp 2001; Gisselquist and van der Meer 2001; Tripp and Louwaars 1997). The absence of such institutions in many developing countries may negatively affect the willingness or ability of private firms to invest in agricultural R&D.

[7] Alfranca and Huffman (2001) find that bureaucratic delays and poor infrastructure quality actually *increase* private agricultural R&D. They suggest, however, that these indicators are negatively correlated with GDP and therefore are simply measuring another dimension of market size, or that higher quality infrastructure allows firms to import agricultural technologies with ease, circumventing the need for in house R&D.

Individual and institutional capacity also play a critical role in stimulating private R&D. Domestic research capacity in developing countries is important in that it accelerates the diffusion and transfer of R&D conducted internationally or in developed countries, as demonstrated in studies by Anderson, Pardey, and Roseboom (1994) and Evenson (1974). While studies such as these often focus on public-sector capacity, the potential spillover effects into private R&D should not be overlooked.

Public-sector research

Private investment in agricultural R&D is also determined by what the public sector does. The cost of private R&D is often reduced by spillovers generated from public-sector research, for example, basic research in concepts and methods, or the provision of the improved germplasm, inbred breeding lines, and foundation seed at nominal costs. In India, Ramaswami, Pray, and Kelley (2002) find that the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) serves as a major source of germplasm for sorghum and millet breeding firms supplying germplasm to nearly 65 and 80 percent, respectively, of private firms covered in their survey. Similarly, public research organizations in India provide germplasm to 66 percent of cotton breeding firms. Perhaps surprisingly, however, Alfranca and Huffmann (2001) suggest a negative effect of public research on aggregate private R&D in Europe, implying public agricultural R&D is crowding out private R&D, at least in their sample of countries.

Technological opportunity

Supply-side (technology) factors can also influence the level of private R&D (that is, R&D conducted by private firms). That is, the more opportunities firms have to transform the available stock of knowledge into commercially viable technology, the more likely they are to invest in R&D activities. For example, advances in the molecular biology, biochemistry, and related fields have resulted in firms making significant investments in agricultural biotechnology.

Exploiting available knowledge to one's benefit by creating new products requires that firms have the capacity to make such a transformation. Firms that are endowed with such a capacity are likely to undertake to more R&D. Lee (2003) finds that technological competencies of firms—as measured by technological capability and the intensity of employee training—is a positive and statistically significant determinant of private R&D. He concludes that since all firms face similar consumer preferences and R&D cost structures, firm-specific technological competencies are possibly the most important determinant of private R&D, the implication being that the distribution of technological competencies determines the allocation of private R&D intensities within an industry.

Firm-specific characteristics

The specific characteristics of a given firm also determine its investment in R&D. Factors that have been shown to influence a firm's ability to conduct R&D include its market value, size, past R&D experience, and sales growth (see for example, the group of papers in Griliches 1984, as well as Griliches 1998). Studies on the determinants of R&D undertaken by private firms have largely been across industries in developed countries, for which data are available. However, it is difficult to generalize the results of such studies because they are clouded by data and methodological problems, and are often not industry-specific or applicable to developing countries. Here we review two representative studies of the life-science industry (pharmaceutical biotechnology), as well as one that examines the determinants of private R&D for the case of a developing country.

For the case the pharmaceutical industry in the United States, Grabowski and Vernon (2000) find that the rapid growth in R&D intensities of drug firms was due in large part to higher expected returns and cash flows. This result has an important implication for public policy toward industrial R&D, as returns to and supply of research funds can be influenced by different types of public interventions, such as regulatory controls, tax policy, and IPR policy, to name just a few.

Another industry-specific study is that of the Canadian biotechnology industry by Cumming and Macintosh (2000). In this study of 56 high-tech firms, the authors find that among the factors that explain greater R&D spending are patent protection, strategic alliances, and the age of the firm—with younger, early-stage firms being more R&D intensive. Firms with high debt–equity ratios and those engaged in research on platform technologies are less likely to spend a greater proportion of their expenditure on R&D. Competition and market demand, however, are not found to be a significant predictor of R&D effort in their study.

Lall (1983) examines the determinants of R&D for a sample of Indian engineering firms, finding that R&D effort is positively influenced by the size, age, and technical absorptive capacity of the firm. R&D is also higher for foreign-owned firms but, surprisingly, not when firms are export-oriented.

4. Push and Pull Mechanisms to Stimulate Private R&D Investment

Extensive literature examines alternative push and pull mechanisms designed to stimulate private R&D. Most studies offer conceptual foundations and application to agricultural research in industrialized countries (such as Alfranca and Huffman 2001; Hall and van Reenen 2000; Day-Rubenstein and Fuglie 2000; Wright 1983). But few studies explore their potential in developing-country agriculture, particularly in the context of research that explicitly addresses crops, traits, and technologies relevant to small-scale, resource-poor farmers and other marginalized agrarian agents.

Incentive mechanisms are needed in developing countries to promote private investment in agricultural R&D, particularly mechanisms that specifically target pro-poor crops, traits, and technologies and distribute benefits, costs, and risks across more than one agent. Incentive mechanisms can be categorized as those that either reduce the costs of R&D and promote basic research to encourage spillovers (push mechanisms) or those that increase the expected returns to R&D by improving or creating favorable market conditions (pull mechanisms). This section reviews the pull and push mechanisms suggested by the R&D literature or commonly used in practice, and examines their performance and impact.

Push Mechanisms

The purpose of push mechanisms is to reduce the cost to firms of conducting R&D and developing new products. These mechanisms take the form of either explicit or implicit subsidies on input costs. They include mechanisms to encourage spillovers from more upstream or basic public-sector research, reduce the cost of capital for R&D, lower the costs associated with meeting regulatory requirements, reduce the risks of product liability, provide tax credits for R&D, provide tariff exemptions for importing key research inputs, or provide R&D grants. Several of these mechanisms are reviewed in detail below.

Public-sector research

While there is much empirical evidence backing the argument that public research spillovers stimulate private investment in R&D, evidence on developing-country agriculture is inconclusive. The issue is whether public-sector research is a complement to or a substitute for private R&D. Resolving this issue is important for shaping research policy: if the second scenario is true, justifying public support for R&D becomes considerably harder.

A review of the literature by David, Hall, and Toole (1999), suggests that the preponderance of evidence, using different levels of aggregation (macro and micro) and methodologies would support the complementarity hypothesis. However, as the authors caution, this observation is simply an unweighted summary of a diverse number studies and not one that is derived from a careful statistical meta-analysis.

In the case of agricultural research, the study by Alfranca and Huffman (2003), demonstrates that public agricultural R&D in Europe might have had a crowding-out effect on private R&D during their sample period (1986–95). This suggests that many European countries have invested in applied research that competes with the private sector, and these countries may not have invested sufficiently in basic research. The authors further argue that the sale of public agricultural research units to the private sector in several European countries (namely, the United Kingdom and the Netherlands) suggests that these countries recognized and responded to this crowding-out effect (Alfranca and Huffman 2003). The substitution effect of agricultural R&D is also observed for the United States, where public applied breeding is found to compete with private breeding.[8] Fuglie and Walker (2001) find that a decrease in public breeding led to a statistically significant increase in private breeding for a given commodity and that the net effect of the increase on private-sector R&D was positive.

While it remains to be investigated whether public-sector agricultural research in developing countries substitutes or complements private research, one might hypothesize that some private research is being crowded out by public research for two reasons. First, most public research activities in developing countries tend to be applied, especially relative to research in developed countries. Second, by its very nature, agricultural research is often applied (for example, plant breeding). Therefore, if public agricultural research is in direct competition with private agricultural research (which is also applied) the potential for a crowding out effect certainly exists. Whether, and to what extent, the current state of low levels of private R&D in developing countries is due to the possible effects of crowding out will need to be empirically examined.

Besides directly supporting research activities in the public sector, public policymakers can enhance the performance and competitiveness of private enterprises by

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[8] This may be the case only with respect to applied plant breeding, given that the study finds complementarities between the public and private sectors in more general plant breeding activities.

providing reliable research infrastructure and support services. For example, support for public research universities would create a pool of highly skilled labor that private firms could readily tap into. Likewise, small firms with limited capacity to conduct their own R&D could leverage the research capabilities of the public sector.

Fiscal policies

Governments can create the necessary financial incentives that lower the cost of conducting research, thereby making investment more attractive to the private sector. For example, governments can reduce corporate taxes or provide tax holidays for those firms that invest in research activities of importance to the country. Subsidies—which can take the form of grants—are another mechanism through which governments can provide investment incentives. Competitive grants, such as those provided by the Small Business Innovation Research program in the United States can be particularly important in pushing the new technology of small companies toward commercialization.

The evidence on the effectiveness of R&D tax credits is strong. Based on a survey of the literature, Hall and van Reene (2000) conclude that in the United States, R&D tax credits produce roughly a dollar-for-dollar increase in R&D spending on the margin, although the schemes tend to have a lagged effect as firms adjust their R&D spending to the incentive. Consequently, many early studies found tax credit schemes to be weak incentives when they were first introduced, though their longer term potential is not insignificant. While there have been relatively few studies examining the effects of R&D tax credits in developing countries, studies from other developed countries such as Australia, Canada, and France draw similar conclusions—that is, that the response of R&D tax credit is small initially but increases over time (Hall and van Reene 2000).

Competitive grants in the context of developing-country private research are discussed by Gill and Carney (1999). Ideally, competitive grant schemes are designed to improve the effectiveness of research expenditure by tying grants to well-defined outcomes and by attracting the most efficient researchers to the task. Gill and Carney

(1999) find that few developing countries have effective competitive grant systems, and that the conditions for success are not being met.

Regulation

Many new technologies—improved seeds, chemical inputs, and especially biotechnology-related products—require safety and efficacy testing before they can be introduced commercially. Regulation serves two broad purposes. First, it instills confidence among consumers that the products being produced are safe for both consumption and the environment (Pray and Naseem 2003). The consumption of GM products in China is a case in point, where it was observed that the simple knowledge that a product was regulated increased consumers' willingness to purchase it (Zhang 2004).

Second, regulation reduces uncertainty and the fears of liability, thereby promoting business confidence and encouraging firms to invest in R&D. A number of authors have lamented that a key reason why biotechnology products have not been adopted more widely is the nonexistence of proper biosafety regulations in many countries (Kent 2004; Cohen and Paarlberg 2002). Kent (2004) reports that in Africa, only 5 of 53 countries have regulations on the commercial release of GM seed. Where biosafety regulations are in place, such as in Brazil, China, and India, the quantity and rate of GM crop approval has been low, partly because of inefficiencies in the biosafety regulatory process that are often perceived as too bureaucratic, nontransparent, or arbitrary. If the regulatory process is too uncertain, cumbersome, or costly, firms may be less likely to undertake research. They may even abandon efforts to seek regulatory approval for technologies already approved in other countries, as was the case with Monsanto's efforts to introduce *Bt* cotton in Indonesia (Chapman et al. 2003).
While weak or absent regulation can create uncertainties and market distortions, overly stringent and costly regulatory requirements can also create similar inefficiencies. Insurmountable regulatory requirements not only prevent the dissemination of new technologies to farmers but also can bias private R&D investments toward those crops that offer lucrative financial rewards (such as, cotton) at the expense of food staples or

other crops of importance to small-scale, resource-poor farmers and other vulnerable social groups. Restrictive regulatory requirements can also act as barriers to entry by small- or medium-sized firms (Spillane 2002). This can result in the lowering of competition in the marketplace, higher prices for end-users, or a slowdown in the rate of innovation.

The barriers to entry are not just a concern for small- or medium-sized firms: where public researchers are the only provider of new technologies, restrictive regulatory requirements can also prevent the dissemination of their R&D efforts. Cohen (2005) reports that, in many developing countries, the public sector is a key source of agbiotech R&D and GM crop development. But much of this work has not moved beyond the experimental stage, due in part to food safety and environmental regulations that public researchers are unable to meet, as well as confusion over regulatory standards for testing.

Research parks and zones

Research parks are property-based policy interventions that provide land and infrastructure to private firms with a promise of external economies of scale and scope (Appold 2004). Often, these external economies accrue by placing research parks close to research universities or government research facilities, or by providing easy access to scientific expertise and equipment in such organizations. Research parks are also used to allow researchers from universities to start their own firms with ideas developed from their own research. Research parks are particularly useful in countries where access to land, expertise, or equipment poses a major barrier for both start-up firms and more established firms in R&D.

Public–private partnerships

Public–private partnerships—broadly described as any joint effort between public and private entities in which each contributes to planning, commits resources, shares risks and benefits, and conducts activities to accomplish a mutual objective—are among the more popular approaches to agricultural R&D discussed in the literature (Chataway 2005;

Spielman and von Grebmer 2006; Byerlee and Fischer 2002; Pingali and Traxler 2002; Pray 2001). Many of these studies examine how pro-poor public–private partnerships can succeed, given alternative organizational structures, incentive schemes, and policy instruments. Findings generally indicate that partnerships succeed only where they are able to manage the costs and risks associated with the exchange and use of knowledge and technologies (particularly where proprietary knowledge is concerned) and where they are able to overcome negative misperceptions across the sectors, identify common goals, and design effective terms for collaboration. However, there is limited empirical evidence as to their performance or outcomes. Pray (2001), Binenbaum, Pardey, and Wright (2001) and Spielman and von Grebmer (2006) examine the role public–private partnerships in the context of national, regional, and international agricultural research systems. Ekboir and Parellada (2002) demonstrate how identifying and combining the right actors can even generate public–private research networks on natural resource management practices, long assumed to be the exclusive domain of public research due to their inherent nonexcludability.

Third-party brokering

Third-party brokers are organizations designed to reduce the costs and risks associated with transferring technologies and tools from the private sector to the public sector, typically for research undertakings on pro-poor crops, traits, and technologies. Brokers include nonprofit organizations, such as the African Agricultural Technology Foundation (AATF), the International Service for the Acquisition of Agri-biotech Applications (ISAAA), and the Public Intellectual Property Resource for Agriculture (PIPRA), as well as advanced research institutes such as the Donald Danforth Plant Science Center and CAMBIA. Many of these organizations play a critical role in facilitating interactions between the public and private sectors, assuming responsibility for the use of proprietary knowledge and technology, and focusing research priorities and execution toward pro-poor crops, traits, and technologies—particularly biotechnology. Little analysis of their role in agricultural R&D has been undertaken, although Naylor et al. (2004) do note their potential in the transfer of proprietary knowledge. However, their contribution to and impact on technology development and poverty reduction remains largely untested.

Pull Mechanisms

The purpose of pull mechanisms is to encourage private-sector R&D by creating a stronger, larger, and more stable market, one that increases expected returns or reduces risks to investment in R&D and the sale of innovative products. These “pull” or demand incentives typically reward private R&D successes by granting monopoly control over their R&D outputs (via IPR), increasing market opportunities through trade, and providing outright payments through advanced purchase agreements and prizes. Pull mechanisms are an attractive alternative for public policymakers because they may choose either to commit resources to promising technologies, or to identify winners in an R&D race.

Intellectual property rights

As discussed earlier, IPR is one of the most powerful pull incentives available to policymakers at present, although its impact with respect to agricultural R&D in developing countries remains ambiguous. IPR includes legal mechanisms, such as patents, plant breeder’s rights, trademarks, and trade secrecy, and biological mechanisms, such as hybridization, genetic use-restriction technologies, and other means of preventing imitation or copying. IPR is designed to create a large and predictable revenue stream for the innovator (albeit for a finite duration) as a form of remuneration. Unlike push mechanisms (like subsidies) or pull mechanisms (like prizes), IPR does not require significant financial outlays by governments and is therefore an attractive—and often a preferred—method of encouraging innovation. Nevertheless, the costs of establishing a regulatory and judicial system to award and enforce IPR are often underestimated.

Laws to protect new plant varieties and biotech inventions spread rapidly to developing countries in the late 1990s. Their spread was accelerated by the introduction of the TRIPS agreement under the World Trade Organization (WTO), which requires

WTO members to establish some type of *sui generis* system of plant variety and patent protection for biotechnology inventions by 2000 (although some developing countries had an extended deadline until 2005). As of mid-2006, 61 states were members of the International Union for the Protection of New Varieties of Plants (UPOV), indicating that they had established some form of plant variety protection.

The TRIPS agreement has also led to a strengthening of patent laws in many developing countries, a trend that may have some impact on agricultural R&D. While a number of countries still exclude novel plants and animals from patent coverage, many do allow patenting of novel microorganisms, including those used in agriculture. The role of IPR in stimulating private research is particularly important for biotechnology research. A number of genes and biotechnological methods are owned by developed-country firms, and the transfer of these technologies will occur if the firms are confident that their intellectual property is adequately protected.

Despite the strong incentive effect of IPR, there is little evidence to suggest that IPR has stimulated *pro-poor* agricultural R&D. This could be for two reasons. First, since most countries have only recently implemented IPR regulations, the likelihood of a lag prior to any R&D effect is high. Second, most developing countries have weak institutions, making the implementation and enforcement of IPR difficult, which renders the IPR ineffective. As such, approaches to strengthening IPR in developing countries must be targeted and realistic if they are to result in innovations that benefit the poor.

Trade and foreign investment liberalization

Agricultural R&D in developing countries is also constrained by trade issues and global market segmentation. Foreign private firms might be willing to invest in small countries if the benefits of new technologies were manifested in the form of greater agricultural output that could be exported to foreign markets where prices are relatively higher. The example of biotechnology is a case in point. Concerns about possible developed-country trade embargos against countries growing GM crops have resulted in restrictions on GM crop cultivation in some developing countries. The European Union, for example, has effectively banned the importation of GM products, which has caused a number of countries, such as Egypt and Thailand, to delay the introduction of GM crops (Kent 2004). Even if some growers choose not to plant GM crops, the import ban would apply to all growers because few countries have proper procedures in place to ensure the segregation of GM and non-GM products.

Countries, therefore, need to carefully consider the cost and benefits of adopting GM crops. In some instances, the premium offered to non-GM exporters is very small relative to the cost-savings from planting GM crops, justifying GM adoption on purely economic grounds (Qaim and Traxler 2002). Furthermore, Nielson, Robinson, and Thierfelder (2001) find that the gains from adopting GM technology are not affected by the anti-GM policies of a few countries because the trade flows of GM and non-GM products are redirected according to the preferences of individual countries.

If the practical experience from trade in United States corn is any guide, then GM-adopting countries could lose market share in GM-free countries but pick up markets in other countries where GM crops are not a concern. The example of GM soybeans in Argentina also suggests that despite GM preferences varying across countries, the competitive advantage provided by considerable cost reductions outweighs any demand-side constraints imposed by GM crop concerns. Argentina has dramatically increased its exports of soybeans and soy products since adopting GM varieties in the late 1990s, and most of these exports go to Europe.

Agricultural R&D in developing countries can also be affected by regulations on foreign direct investment. A foreign firm's choice to invest in a country—and to undertake R&D in that country—is often determined by the extent to which the firm can maintain effective control over the R&D process, including (but not limited to) its intellectual property. By way of example, the growth in private R&D investment in India is due in large part to the liberalization of its agricultural input markets and openness to foreign direct investment (Pray, Oehmke, and Naseem 2005).

Advance purchase commitments, rewards, and prizes

By promising to purchase predetermined quantities of a specific technology at an agreed price, governments and donors can help private firms overcome the small market problem. Advance purchase agreements (also known as advance contracting) are not only useful for products in the advanced stages of development, but also those in the earlier stages of the research process.

However, advance purchase agreements rely on the strength, credibility, and enforceability of the contract. Firms face the risk of a sponsor withdrawing from the agreement, or pressuring the firm to sell the product at a price lower than agreed on (for example, during a humanitarian crisis). The sponsor may also face risks that result from difficulties in anticipating demand for the product or in structuring the contract (compensation, timeframe, quality evaluation, and so on).

Financial prizes or rewards for technology development are another mechanism that can be used to encourage private investment in agricultural R&D. Rewards and prizes are discussed in detail by Masters (2003) and Kramer and Zwane (2005). In essence, they argue that prizes can be awarded for pro-poor innovations (for example, improved crop varieties), and that innovators should be paid in proportion to the social returns of their technologies, as determined by third-party assessments of farmer adoption rates.

Rewards, prizes, and advance commitments have one key element in common: they are all designed to elicit supply responses to demand. In other words, these mechanisms attempt to create a market (typically through donor or public financing) where one might not otherwise exist.

The social welfare impacts of these various mechanisms have yet to be evaluated. Wright (1983) provides one of the earliest theoretical comparisons of the social welfare properties of patents, prizes, and direct contracting for research services in the presence of asymmetrical information. Theoretical findings suggest that the best incentive scheme depends on the appropriability of knowledge, the size of the deadweight losses, and the effects of the common pool problem. However, empirical tests of these theories, particularly with reference to innovation in developing-country agriculture, are largely absent.

5. Setting a Research Agenda for Pro-Poor Private R&D

Table 6 summarizes the arguments discussed in the previous section and outlines an agenda for research on pro-poor private agricultural R&D. The key point to be recognized is the large number of inconclusive relationships inherent in these mechanisms. Very little is known about how a particular push or pull mechanism will work under a given set of circumstances. Also evident is that, despite the diversity of mechanisms described in the literature, few have been implemented in developing countries. For example, the Consultative Group for International Agricultural Research (CGIAR)—arguably the body most logically placed to engage multinational firms in collaborative research initiatives—has invested surprisingly little in public–private partnerships in agbiotech R&D (World Bank 2004; Spielman and von Grebmer 2006). Furthermore, very few of the mechanisms implemented to date (for example, competitive grants and third-party brokering) have been subjected to extensive monitoring, evaluation, or impact assessment.

Table 6: Push and pull mechanisms for spurring private R&D

Mechanism	Type	Examples	Hypothesized impact on private R&D
Public-sector research	Push	Support for basic scientific research	Inconclusive: positive if complementary; negative if substitutive (crowding out)
Fiscal policies	Push	Tax credits, tax holidays	Positive with lagged effect; small initially, but increasing over time
Regulatory improvement	Push	Testing and certification	Inconclusive: positive if efficient and transparent; negative if overtly stringent and costly
Research parks and zones	Push	Provision of land and infrastructure near universities	Positive; typically help investors to overcome major entry barriers
Public–private partnerships	Push	Public seed development, private seed distribution	Inconclusive: successful only where conflicting incentive structures; high transactions and opportunity costs; risks associated with the use of proprietary assets; and mutually negative misperceptions can be properly managed
Third-party brokering	Push	Non-profit organizations like the African Agricultural Technology Foundation	Inconclusive: positive if the costs and risks associated with transferring technologies and tools between the private and public sectors can be reduced
Intellectual property rights	Pull	Patents, plant breeders' rights, trademarks, trade secrets	Inconclusive: impact depends on the nature of the IPR mechanism and the presence of supporting institutions
Trade liberalization	Pull	Lifting of trade embargoes	Inconclusive: Firms and countries may lose market share in some areas but gain it elsewhere
Advance commitments	Pull	Predetermined purchase promises	Inconclusive: depends on the presence of enforcement institutions; it is difficult to predict future costs and demand
Rewards and prizes	Pull	Financial prizes for research discoveries	Inconclusive: depends on the appropriability of knowledge, size of deadweight losses, and effect of common pool problems

Still, there is no question that pro-poor agricultural R&D in developing countries requires an enabling environment for private-sector participation and investment. Many of the key elements of an enabling environment are well established, but they are still worth mentioning here. They include improvements in varietal registration procedures, biosafety regulation processes, and IPR enforcement at the national level; improvements in physical and communications infrastructure to accelerate the flow of knowledge among researchers; privatization of state-owned input supply firms; and harmonization of regional and international regulations to create larger markets for private investment in agricultural R&D.

What remains unclear is the relative importance of these different elements in an enabling environment. More empirical evidence is needed on the relative importance of the different elements, the incentive mechanisms that can enhance the performance of each element, and the specific contexts in which performance can be enhanced. More empirical evidence can assist policymakers in designing policies that place pro-poor agricultural R&D at the forefront of national science and technology agendas.

As mentioned earlier, the lack of reliable informative data on private-sector R&D in developing countries poses a critical constraint to bridging this knowledge gap. Data that are available tend to be limited, ad hoc, and rarely conducive to comparative analysis across countries. This includes data on private investment in agricultural R&D, as well as performance data on various push and pull mechanisms, where they exist. For example, recent attempts by the International Food Policy Research Institute's Agricultural Science and Technology (ASTI) initiative to collect data on private-sector R&D has had limited success due to an inadequate response rate from surveyed firms.

This suggests the need for a research program on private investment in pro-poor agricultural R&D. Such a program would gather detailed information on private-sector R&D activities in selected countries to measure the amount of agricultural R&D being conducted, the nature of the R&D being conducted, and the relevance of the R&D to poverty reduction. Key focal points for data gathering would include investment levels for research on new technologies; expenditures on personnel and infrastructure; ownership patterns of firms conducting agbiotech R&D and the knowledge and other inputs they use; responses to the push and pull mechanisms mentioned above, where they exist; and the use of partnerships, alliances, networks, and other collaborative modalities. These data can improve our understanding of the ways in which agricultural R&D is tempered by alternative policy frameworks and incentive mechanisms.

A research program along the lines set forth above would combine detailed country case studies based on key informant interviews, with cross-country comparisons based on econometric analyses. The combination of qualitative and quantitative methods would shed new light on the impact of alternative policies and mechanisms in agricultural R&D. Ultimately, such a program could provide policymakers with an understanding of the options and tradeoffs available to promote private investment in pro-poor agricultural R&D.

6. Conclusion

Continued public and private investment in agricultural R&D is critical to the production of new technologies to enhance agricultural productivity and reduce poverty in many developing countries. To date, however, the potential of the private sector has yet to be realized, particularly with respect to the production of technologies that are explicitly relevant to small-scale, resource-poor farmers and other vulnerable social groups. Private-sector investment in agricultural R&D remains low in developing countries, and persistently overlooks those crops, traits, and technologies that are vital to livelihoods of the poor.

While there are many market and institutional factors that explain the low rates of private investment, a number of incentive mechanisms would stimulate private investment. Push and pull mechanisms that stimulate both the demand for and supply of private R&D—if carefully designed, adequately funded, and politically backed—could generate desirable stimulus effects. However, what remains to be seen is which measures are most effective, and under which circumstances, Further research is needed to shed new light on these incentive mechanisms and their impact on private investment in pro-poor agricultural R&D.

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