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Accessing Modern Science: Policy and Institutional Options for Agricultural Biotechnology in Developing Countries

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Summary. — The private sector dominates biotechnology research in industrialized countries, but there are major market failures in developing countries in accessing the new tools and technologies. The public sector, national and international, will have to play a major role in filling this gap. This paper provides an overview of options that countries of different sizes and capacities can employ to gain access to the research tools and technologies that they need to address issues of relevance to poor producers and consumers. Particular attention is given to how public–private partnerships and market segmentation are being employed to access proprietary tools and technologies. © 2002 Elsevier Science Ltd. All rights reserved.

Key words — biotechnology, agricultural research, intellectual property rights, national agricultural research systems, developing countries

1. INTRODUCTION

Modern biotechnology based on molecular biology is generating revolutionary advances in genetic knowledge and the capacity to change the genetic makeup of crops and livestock. The rapidly expanding field of genomics is providing new molecular tools to greatly accelerate and more precisely target conventional breeding. This same knowledge is being applied to transfer genes across (and within) species to create transgenic varieties (popularly known as genetically modified organisms). These new approaches require advanced skills, research laboratories, the capacity to manage intellectual property (IP) and, in the case of transgenics, to evaluate environmental and health risks.

Recently a number of influential organizations and individuals have provided strong endorsement that modern biotechnology has significant *potential* in developing countries to raise agricultural productivity in a more environmentally friendly manner, enhance food security, and contribute to the alleviation of poverty (Royal Society of London, 2000; Nuffield Council on Bioethics, 1999; Pinstrup-Andersen & Cohen, 2000; Serageldin & Persley, 2000; Spillane, 2000). This potential is particularly relevant given the enormous challenge of increasing food security in the developing world, and the growing evidence that gains from conventional sources of technology are slowing.

To date, application of molecular biotechnology has been limited to a small number of traits of interest to commercial farmers, mainly developed by a few "life science" companies operating at a global level. Very few applications with direct benefits to poor consumers or to resource-poor farmers in developing countries have been introduced. Although much of the science and many tools and intermediate products are transferable to solving high-priority problems in the tropics and subtropics, it is generally agreed that the private sector will not invest sufficiently to make the needed adaptations.

Consequently, national and international public sectors in the developing world will have to play a key role, much of it by accessing

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proprietary tools and products from the private sector. There has however been little detailed analysis of the incentives and mechanism by which such public–private partnerships can be realized.

The aim of this paper is to provide a broad framework for assessing a range of policy and institutional options available to developing countries for generating and accessing the new molecular tools, at the national, regional and global levels, with particular emphasis on crops. After a synoptic overview of the status of biotechnology research in, and for, developing countries, various mechanisms for accessing modern tools and technologies are outlined and analyzed for their potential cost effectiveness, using available examples. The main section of the paper discusses policy and institutional options for facilitating this transfer within a framework of public and private bargaining chips and segmented markets. Special attention is given to how strategies can be adjusted to fit the very different capacities among developing countries in biotechnology research.

2. CURRENT STATUS OF BIOTECHNOLOGY RESEARCH IN DEVELOPING COUNTRIES

Biotechnology research is currently being carried out in both public and private organizations, which may have either national or multinational mandates.

(a) *The private sector*

There is little doubt that the private sector is the major player in biotechnology research globally. The major life science companies invested some $2.6 billion in agricultural research and development (R&D) in 1998 (www2.aventis.com/introduce/rddia_2.htm), with perhaps $1.5 billion of this allocated to plant biotechnology research (CGIAR, 1997). [1]

A small share of this private R&D is directed at developing countries. Much of the this is occurring through direct investment by the global life science companies, acquisition by these companies of seed companies in developing countries, and through alliances between global and local companies. Through these mechanisms, each of the major life science companies has a significant presence in the developing world, although this is highly concentrated in a few large countries.

A second group of private firms is the smaller biotechnology companies that specialize in biotechnology research. While most of these are located in the industrialized world, and many work through partnerships with the global life science companies, they own tools and products and have specialized skills that are often relevant to developing world problems. This group has however little direct investment in developing countries, except for a small number of companies located in a few large developing countries.

Finally, there are also important local seed companies that carry out R&D in developing countries, although many have been acquired in recent years by the global companies. Only a few local companies have a capacity in biotechnology research, and in nearly all cases, their research is carried out as part of an alliance with one of the global companies.

The private sector has focused its investments on commercial agriculture in the industrialized countries and a few developing countries. But, the private sector is also a major player in developing countries for R&D on hybrid crops, such as maize, even in markets with relatively small farmers, such as Central America and the Andean Region (Morris & Lopez-Pererra, 1999). For nonhybrid crops, private companies are mostly conducting biotechnology research in a few developing countries with large seed markets and where intellectual property rights (IPRs) can be enforced (Teng, Stanton, & Roth, 2000).

(b) *Public sector national agricultural research systems in developing countries*

There is a huge diversity among national agricultural research systems (NARSs) in developing countries with respect to their capacity in agricultural biotechnology R&D. Table 1 presents a highly simplified view of differences in capacity of national research systems in biotechnology research, divided into three broad groups;

(a) A few type I NARSs (India, China, Mexico, Brazil, and South Africa), which have strong capacity in molecular biology, including ''upstream'' capacity often located in universities, to develop new tools for their own specific needs.

(b) Type II NARSs which are a group with capacity to apply molecular tools (markers and transformation protocols) developed elsewhere.

Table 1. *Summary of plant breeding and biotechnology capacities of different NARSs types*

	Type 1 NARSs—very strong	Type II NARSs—medium to strong	Type III NARSs—fragile or weak
Markets size in terms of potential R&D impacts	Large to very large	Medium to large	Small to medium
Plant breeding	Strong national commodity programs with comprehensive breeding programs, including some pre-breeding	National commodity programs that are generally strong in applied breeding	Usually small and fragile programs with success dependent on one or two individuals. Mostly direct releases after local screening and testing of international germplams, especially from the CGIAR
Biotechnology research	Capacity in molecular biology as great or greater than most IARCs; marker-assisted selection being incorporated into breeding programs; considerable research on transgenics; growing capacity in genomics and participants in international genomics networks	Usually developing capacity in molecular biology but with considerable support from donors and IARCs; potential to participate as partners in genomics in screening germplasm	Very little or no capacity in molecular biology although many have capacity in tissue culture
Private sector	Private sector very active for hybrid crops and increasingly for nonhybrid commercial crops	Private sector activity increasing and usually involved in hybrid crops	Little private sector activity for food crops
Regulatory framework for biosafety and IPR	Framework in place although capacity to implement is modest and untried	Most countries have, or soon will have framework, but weak capacity to implement	Most countries do not have regulatory framework

(c) A large group of type III NARSs, with no capacity in molecular biology and very fragile capacities in plant breeding. These countries largely depend on introduction and testing of varieties from abroad, especially from the Consultative Group on International Agricultural Research (CGIAR) system.

Most type I and II NARSs have also developed regulatory frameworks for biosafety testing of transgenic crops and to protect IP, although capacity to evaluate risks and to manage IP is often weak. Most type III NARSs do not have a regulatory framework in place to even import and test transgenic products. On average, NARSs (types I and II) invest 5–10% of their total research expenditures in agribiotechnology (Janssen, Falconi, & Komen, 2000) concentrated in type I and a few type II countries. In four countries where detailed data are available (Kenya, Mexico, Indonesia, and Zimbabwe), public sector organizations, including universities, accounted for 92% of research expenditures on agricultural biotechnology during 1985–97 (Janssen *et al*., 2000). No estimates are available on overall investments by NARSs in biotechnology, but given available data, a rough guess is that they are investing US$ 100–150 million annually from their own resources (i.e., excluding donors)—several times the investment of the CGIAR.

(c) *Public research organizations and universities in industrialized countries*

Public organizations and universities in the industrialized countries carry out a considerable amount of biotechnology research, with a small amount oriented toward developing country agricultural problems (usually funded by donors). Many of their tools and products are potentially useful to developing countries but developing-country access to them is restricted by the strong trend in these public organizations to protect and market their IP, and

the increasing number of alliances between these organizations and the private sector.

(d) *The Consultative Group on International Agricultural Research*

Collectively, the CGIAR centers invest around US$25 million annually in biotechnology, representing 7.7% of the total CGIAR budget (Morris & Hoisington, 2000). With a relatively small investment, the CGIAR has made substantial progress in applied biotechnology research aimed at selected traits and crops that complement private-sector efforts. Once their own capacity has been established, centers are turning to capacity building and networking in client countries. IARCs have however invested little in strengthening capacity in policy and regulatory issues related to deployment of biotechnology products, and have shied away from active participation in public dialogue surrounding transgenics (Morris & Hoisington, 2000).

(e) *Donor support and multinational initiatives*

Donors provide between US$40 million and US$50 million per year for agri-biotechnology not including the US$25 million spent by the CGIAR on biotechnology (Horstkotte-Wesseler & Byerlee, 2000). This investment however is concentrated in just a few countries, nearly all with type I and II NARSs. The focus of this support varies substantially from directly funding research (e.g., the Rockefeller Foundation), supporting public–private partnerships and technology transfer (e.g., USAID), capacity building (the World Bank), and participatory needs assessment (the Netherlands).

There are also a number of multidonor global initiatives, including the Intermediary Biotechnology Service at ISNAR, the International Service for the Acquisition of Agri-biotech Applications (ISAAA) at Cornell University, and the Center for the Application of Molecular Biology to International Agriculture (CAMBIA) in Australia, which conduct research, develop capacity and facilitate technology transfer.

While the amount of donor funding for biotechnology is relatively small, these funds constitute a considerable proportion of total public investment in agricultural biotechnology R&D in developing countries, outside of the three "NARS giants"—India, China and Brazil. But, the effectiveness of donor support has been limited by; (i) fragmentation and "projectization" of donor efforts with no clear international consensus on priorities to guide a coordinated multilateral effort on traits for the poor, (ii) overemphasis on technology development at the expense of investment in national regulatory systems and public dialogue to facilitate in-country testing and risk evaluation, and (iii) a focus on public sector investments with little attention to accessing currently available tools and technologies from the private sector (Horstkotte-Wesseler & Byerlee, 2000).

3. MECHANISMS FOR ACCESSING TECHNOLOGY IN AN ERA OF PRIVATIZATION

A central issue for both public and private sectors, is that many of the biotechnology tools and products of potential value to resource-poor farmers and consumers have complex patterns of ownership in which there is an increasing web of crosslicensing, mergers, and ownership of the components of a given technology. The case of enhanced vitamin A rice, which is reported to be based on technologies protected by up to 70 patents originally held by 31 different organizations, highlights the complexity of ownership pedigrees (Kryder, Kowalaski, & Krattiger, 2000). Each owner of the component technologies will have different expectations for the use of his/her technology in different countries and in different markets. The process is further complicated by the fact that individual component technologies may be protected in some countries but not in others.

We discuss below four broad options for public policy in developing countries to facilitate access appropriate knowledge, tools, and products. The relevance of each option is very case specific, depending on the type of NARS, the crop, and the trait of interest.

(a) *Leaving it to the private sector*

The first option that should be considered in accessing the relevant knowledge and technologies, is to promote technology transfer through the private sector. It is commonly stated that the private sector will only invest for commercial markets. There are several reasons however to expect that the future role of the private sector in developing countries may be underestimated. First, the marginal cost of

moving some tools and technologies originally developed for commercial markets, into emerging markets may be low. Second, the policy environment for the private sector in developing countries is being liberalized leading to rapidly increasing private sector activity in seed markets. Third, biotechnology itself will in the medium term, facilitate protection of IP, especially in markets for small-scale farmers where it is not cost effective to enforce IPR laws at the farm level. Trait-specific technology protection systems—biological/chemical approaches to IP protection that allow trait expression only through application of a proprietary chemical—as well as application of biotechnology to increase the efficiency of hybrid seed production in self-pollinated crops such as rice and wheat, are being developed by the private sector.

But outside of specific crops and regions, the role of the private sector will also be limited for the foreseeable future. Private firms under-invest in agricultural R&D due to well-known market failures such as spillovers and difficulties of appropriating benefits of research. Market failures are endemic for biotechnology (Rausser, 1999) and especially for resource-poor farmers in developing countries, due to a number of special characteristics of biotechnology research. These include the high fixed cost of much of the research, the need to operate in large markets to recuperate fixed costs, and poorly developed seed markets in developing countries. Several market failures also occur in accessing and protecting IP, including weak IPR laws for biological inventions in most countries, high cost of enforcement of IPRs in small-scale agriculture, the complexity and fragmentation of IPRs leading to high transactions costs to negotiate licenses, and ill-defined rights on the scope of biotechnology inventions. Finally for transgenic products, there are likely to be high *initial* costs of the development phase owing to costs of passing early technologies through biosafety and food safety regulations (because of inexperience and in some cases, negative public perceptions), as well as considerable informational requirements for farmers to adopt these technologies (Tripp, 2001).

These various types of market failures mean that the public sector will have to play an important role in serving resource-poor farmers, at least in the initial stages. But the private sector can be expected to play a lead role for commercial crops, such as cotton, hybrid crops (maize and some oilseeds), and single-trait transgenics for pest resistance and herbicide tolerance in favored areas, even for quite small-scale farmers. An important policy issue is to ensure that the public sector complements private R&D. Public research is often critical to reduce cost of entry for private firms (Pray & Umali-Deininger, 1998). Once a competitive private-sector market is operating, the public sector can redirect those resources toward farmers and environments that are not being targeted by the private sector, and backstop private sector research with longer-term research on complex traits with more uncertain outcomes.

For agricultural research in general, and for biotechnology in particular, most public sector organizations have yet to formulate a strategy to complement private sector research. For example, Hossain, Bennett, Datta, Leung, and Khush (2000) found that a large proportion of the rice biotechnology projects in the public sector addresses many of the likely targets of the private sector, especially insect and disease resistance and herbicide tolerance in favorable ecosystems. But the public sector is gradually increasing attention to abiotic stresses and yield and nutrition traits that appear to receive less attention in the private sector.

(b) *Relying only on the public sector*

Another option is for the public sector to develop a program independently of the private sector by "designing around" protected tools and products through its own inventions that do not infringe on the IP of others. This might be possible and even efficient if the cost of the research is less than the cost of accessing equivalent technologies from elsewhere. It is most likely to be applicable for specific tools and technologies to fill gaps in a tool kit acquired by a variety of means, and that will be used to develop finished products (e.g., varieties). Since a considerable number of tools are needed for even relatively simple genetic transformations, it is not likely to be efficient in terms of resource use and time to develop a complete tool kit free of IP encumbrances.

Closely related is the possibility of redesigning the components of a product to reduce the number of patents that need to be negotiated on a desired product. The recent review of the IP profile of enhanced vitamin A rice by (Kryder *et al.*, 2000) found considerable potential to carry out further research to redesign

components in order to reduce the cost and complexity of IP negotiation. But, costs of the additional research need to be balanced against costs of IP negotiations. Finally, there are some public domain technologies available in industrialized countries which are freely available, and many of which are potentially useful for developing countries (Spillane, 2000). The number of such technologies may increase as patents expire for first generation technologies. These various options for designing around proprietary tools and products should definitely be explored but their feasibility will likely be limited to a few tools and products in type I NARS.

(c) *Accessing proprietary technologies*

The third major option is for the public sector to access proprietary tools and technologies, usually from the private sector but sometimes from other public organizations. Opportunities for the public sector to access proprietary tools and technologies will differ widely depending on the technology, its use in commercial or noncommercial markets, and the business interests of the owners. Several business and legal options have been used by the public sector to gain access to proprietary technology, such as joint venture, secrecy agreements, licensing, purchase, and material transfer agreements (MTAs).

(i) *Unilaterally accessing technologies*

One option is for the public sector to unilaterally access a tool or technology, especially those technologies that can be easily copied, such as a specific gene from a transgenic variety, without seeking permission of the owner. This is often perfectly legal if patents for the technology have not been lodged in the country where the technology will be used, and provided that the product is not exported to a country where there is protection on the invention. This is most likely to occur in countries with type III NARS. In reality, however, many critical and enabling technologies for biotechnology have been widely patented in many countries, especially with type I and II NARS, making it essential to gain the freedom to operate before releasing a new product.

A recent review of the patent pedigree of enhanced vitamin A rice (Kryder *et al*., 2000) provides good insights into the pattern of patent protection (Table 2). While they identified 44 potential patents related to this rice in the United States, the number of relevant patents in developing countries varies by country from 0 to 11. All type I NARSs would face patent restrictions, although there is no clear relationship between the number of potential patents, the importance of rice, and the strength of the public sector research program. No patents have been taken out or filed in Thailand (a country with intermediate capacity in biotechnology), while patents have been taken out or filed for several of the components in countries with little capacity in molecular biotechnology (e.g., in some African countries). But, even Thailand and other countries (Pakistan and Uruguay) with no relevant patents would face difficulties in employing the option of unilateral access since they are major rice exporters to countries where patents are held.

Table 2. *Number of patents on vitamin A rice, level of rice production and percentage exported, by country*

Country	Rice production (Mt), 1998	% Exported 1998	Number of patents
China	200.6	1.9	19
India	127.5	3.8	5
Indonesia	49.2	4.0	6
Bangladesh	28.3	0	0
Vietnam	29.1	13.1	9
Thailand	22.8	27.9	0
Myanmar	16.7	0.6	0
Japan	11.2	0	21
Philippines	10.2	0	1
USA	8.5	36.5	44
Brazil	7.7	0	10
Pakistan	7.0	26.6	0
Egypt	4.5	9.6	0
Nepal	3.6	0	0
Nigeria	3.3	0	0
Côte d'Ivoire	1.4	0	10
Uruguay	0.9	75.4	0
Senegal	0.1	0	0

Source: (Kryder *et al*., 2000) and FAO statistics (www.fao.org).

Even when strictly legal, unilateral access has a number of limitations; the complexity of many tools that does not allow easy copying; scientists also need to access associated "know how" and training for effective use of the tools; rapid advances in science will likely leave the public sector working with outdated tools; several partners are often involved in transfer of a tool or technology and the reputation and IP status of all partners must be considered; and unauthorized access limits exports of derived products, although this would affect only a small share of staple food production

(Binenbaum, Nottenburg, Pardey, Wright, & Zambrano, 2000). Nonetheless, for many type III NARSs serving smaller markets, and for orphan crops, unilaterally importing transgenic varieties or crossing with local materials without considering IP, may be the most cost-effective approach to accessing the technology since it avoids establishing expensive laboratory and IP management capacity.

(ii) *Purchasing outright*

Another approach is for the public sector to buy ownership of key proprietary technologies for use in developing countries. For example, a consortium of public sector institutions in Asia, led by IRRI, purchased the rights to a Bt gene owned by a private Japanese company. The consortium then decides whether to make these materials public property or allow others to use the gene, subject to royalty payments. Likewise Cohen, Falconi, Komen, Salazar, and Blakeney (1999) report over 50 instances in which Latin American NARS have purchased tools and products.

A variant of this approach would be to contract with the private sector (or a public supplier), perhaps through competitive bidding, to *develop* a specific tool, but with the public sector retaining ownership of the product. This is most appropriate where the know-how exists in the private sector to adapt a product to a specific situation with considerable certainty. It also requires international funding (such as a global fund discussed below) since few NARSs have sufficient resources to interest the private sector.

(iii) *Material transfer and licensing agreements*

MTAs are often used to define conditions for transfer of research materials and tools for use in research only, leaving the need to develop a license for commercial use of final technologies to a later stage. MTAs that define ''front-end decisions'' (Rausser, Simon, & Ameden, 2000) on priorities and resource contributions are favored by public research organizations, since up-front costs are minimal, and risks are reduced by the fact that negotiation of the use value occurs after the value of the product, if any, is known. But this practice can also weaken the negotiating position for licensing for the use phase, since the greater the success of the research, the greater the value of the technology and therefore the greater the expectation of returns by the owner. In some cases, this has slowed the flow of research products to users after considerable investment in product development, due to failure to reach agreement on the ''back-end decisions'' on commercialization and royalty sharing, satisfactory to all sides.

Licensing is the most widely used method to transfer technology and associated know how, under a contractual agreement *on use* of resulting products and sharing of benefits from their commercial application. Crosslicensing is also often used to allow parties to exchange technologies. Licensing requires considerable skills in IP, negotiation, and business planning, and often entails high transactions costs due to the complexity of IP pedigrees.

(d) *Alliances and joint ventures*

Alliances and joint-venture agreements usually involve licenses and MTAs for sharing and accessing technologies. In joint ventures, each party, public and private, contributes specifics assets or knowledge, and shares benefits according to an *a priori* agreement. Joint ventures between the public and private sectors are becoming more common in accessing biotechnology tools in developing countries.

The number of different types of potential alliances for biotechnology research is enormous. Simply considering only two-way alliances among major categories of actors, public and private, and national and international, and adding advanced public research institutes and smaller biotechnology companies (mostly located in industrialized countries), all possible combinations are possible and in fact most are found in practice (Figure 1). The potential for three- or even four-way alliances among categories complicates the issue even further. Thus the number of options open to public sector NARSs in accessing technology through alliances is very large.

One example is a joint venture between Pioneer Hybrid, a large private multinational company (now acquired by Dupont), and the Applied Genetic Engineering Research Institute (AGERI), an Egyptian public research institute, to jointly develop Bt maize. A different type of joint venture, and one widely used in the industrialized world, has been developed between Monsanto and the Indian Institute of Science in which the public sector is carrying out basic research upstream in the technology chain. CGIAR centers are also developing a number of joint ventures and agreements with private companies (e.g., CIMMYT, 2000).

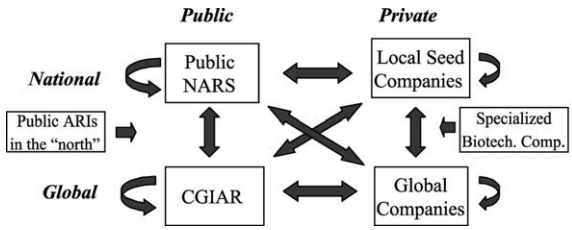

Figure 1. *Potential partnerships in biotech R&D.*

Although conceptually simple, alliances and joint ventures between the public and private sector often require considerable nurturing due to differences in business cultures and lack of experience with IP management in public organizations. An intermediary institution has often been useful in facilitating an agreement, as is the seed funding provided by that institution.

4. PUBLIC–PRIVATE PARTNERSHIPS, COMPLEMENTARY ASSETS AND MARKET SEGMENTATION

It is clear from the above discussion, that the public sector will have to play a key role in biotechnology R&D in developing countries, but that the public sector working alone will make slow progress. Thus public–private partnerships will be a central element of any R&D strategy. Negotiation of successful public–private partnerships revolves around defining goals, identifying complementary assets, and analyzing the potential to segment markets for different partners (Rausser *et al*., 2000; Van der Meer, 2002). Public and private partners also need to recognize important differences in their values and culture. With experience, the cost of negotiating such partnerships should fall (Van der Meer, 2002).

The stated goal of most public research organizations is to maximize societal benefits, usually defined in terms of economic benefits, including benefits to the poor, although the reality may be different depending on internal incentive structures and external political pressures. Private firms operate to maximize profits within acceptable levels of risks in order to provide good returns to their shareholders and protect their competitive edge. Within these distinct goals, negotiation revolves around defining complementary assets and segmenting markets.

(a) *Defining complementary assets*

Both public and private sectors bring specific skills and assets that should provide the potential for alliances that exploit complementarities between them. Table 3 shows potential assets of public and private sectors at both the national and international levels. Assets of the public sector include its germplasm and evaluation networks, local knowledge, applied breeding skills and infrastructure, and access to a seed delivery system and public sector extension. Global life-science companies have assets in the form of biotechnology tools and genes, and access to international capital markets. Even public confidence in a research organization or firm may be considered an asset. In the case of biotechnology, global companies are sometimes perceived negatively by the public, while many public-sector organizations enjoy positive perceptions. On the other hand, the private sector may have assets in terms of flexibility in decision making that speeds up R&D.

One of the major bargaining chips available to the public sector is access to and especially its knowledge of germplasm and associated evaluation networks in developing countries. In the past, the national and international plant-breeding systems depended on free access to germplasm, both genetic resources as well as developed cultivars. Clearly, public NARSs will have to develop new strategies that balance the gains from continued free flows of germplasm against the potential to use this germplasm, especially locally adapted materials, as a bargaining chip (Falcon, 2000). The value of their germplasm and associated knowledge is being enhanced by the rapid advances in functional genomics that require access to and knowledge of genetic diversity that is available in the public research organizations.

In a reversal of the situation in industrialized countries, public–private complementarity in

Table 3. *Assets of public and private sectors in agri-biotechnology research*[a]

	Public sector	Private sector
National level research organizations	Public NARSs	Local seed companies
Key assets	—Local diverse germplasm —Local knowledge —Breeding and evaluation programs and associated infrastructure —Access to delivery system including extension —Upstream capacity (type I NARSs only) —Mostly positive public image	—Local knowledge —Breeding programs and infrastructure —Seed delivery system —Marketing network
Regional and global level organizations	CGIAR International Centers	Global life science companies
Key assests	—Diverse germplasm —Breeding programs and associated infrastructure —Global germplasm exchange and evaluation networks —Economies of market size —Upstream capacity in a few centers —Mostly positive public image	—Biotechnology tools, genes, know how —Access to captial markets —Economies of market size —Skills in dealing with regulatory agencies —Flexibility and speed in decision making

[a] For simplicity, advanced research institutes in industrialized countries are excluded from the table, but they have many of the same assets as other public organizations. Similarly, specialized biotechnology companies could be included for the private sector.

assets in developing countries tends to be with the private sector upstream (knowledge, tools, technologies) in the technology chain, and the public sector downstream (adaptation and delivery). But, there are some advanced laboratories in the developing world, where the public sector may have complementary upstream skills, akin to the case in the industrialized countries (e.g., the Novartis-University of California, Berkeley alliance). These advanced public research institutes may have bargaining chips in the form of molecular tools that they themselves develop. This underlines the importance of public research organizations developing capacity to protect their IP, even if income generation is not the primary objective.

(b) *Segmenting markets*

Market segmentation is one way that public and private sectors might exploit their asset complementarities through alliances such that the public sector serves resource-poor farmers, leaving commercial farmers to the private sector. In principle, the public sector may be able to negotiate a nonexclusive licenses for use of the technology at no or low cost in certain markets—marginal areas, resource-poor farmers, and orphan crops—that are not of interest to the private sector but where it may enhance the public relations image of private firms. The same technology would be prohibited under the license from being commercialized in other "more market-oriented areas." A reasonable goal for the public sector might be to license a product needed for research and use at zero royalty in noncommercial markets, and at a fair and reasonable price for emerging markets, leaving commercial markets to the private sector.

Segmentation of markets must be decided on a case-by-case basis. Logically it would be desirable to differentiate by type of farmer but this raises practical difficulties in implementation. Various "proxy" criteria have been used for market segmentation including the type of crop, specific varieties, regions, trade status, and country-income level. Table 4 provides examples of how these criteria have been employed in practice in several public–private licensing agreements.

Table 4. *Examples of different types of market segmentation*

Criteria for segmentation	Example
Crop and region	The Monsanto and Kenyan Agricultural Research Institute agreement for a transgene for control of African sweet potato virus disease allows unrestricted use in sweet potatoes in Africa (Wambugu, 1996). Insect resistant maize with proprietary technologies from Novartis is being transferred from CIMMYT to Africa but cannot be used outside of the region.
Variety	The transfer by Monsanto of genes for virus-resistant potato is restricted to selected varieties of potatoes grown by small farmers in the central part of the country (Qaim, 1998).
Country income level	IRRI negotiated the rights for use of stem borer resistance gene for rice from Plantech for all developing countries, as defined by the UN
Trade status	The transfer of genes in papaya provide by Zeneca for delayed ripening and for virus resistance by Monsanto, in Southeast Asia, is license free for production destined to the domestic market with the right to negotiate a commercial license for export production.

Although market segmentation is a conceptually appealing way for the public sector to gain access to proprietary technologies, there are major practical hurdles to overcome. First, many developing countries have a growing potential private market for technologies and to be effective in larger countries, market segmentation must be *within*, as well as across countries—a much more difficult legal and administrative challenge. Second, technology frequently spills over, often in unexpected ways, to other regions and farmers, and the containment of the IP to the market in question may be difficult. Third, competing firms may gain access to the technology for use in other markets where the IP is not protected, reducing the incentive for private firms to license their materials. Finally, issues beyond IP, such as responsibility and liability for risks incurred are becoming important in gaining access to technology for noncommercial markets.

In practice market segmentation often requires intense negotiation, the development of trust between partners, and capacity to enforce agreements on markets. The result will generally require compromises that introduce imperfections. Market segmentation will become more common and will succeed best where there are few IPs and owners involved, where noncommercial markets can be sharply delineated by region, and where it will be easy to exclude spillovers to nontargeted markets. The public sector will however need to be realistic about what can be achieved *free* of royalties—the strategy to date—and be prepared to consider payment of *reduced royalties* to maximize access to appropriate technologies.

5. POLICY AND INSTITUTIONAL OPTIONS TO FACILITATE TECHNOLOGY TRANSFER

The ultimate aim of public policy should be to promote "access to the most advanced beneficial technologies available on the best available terms" (Barton, Lesser, & Watal, 1999, p. 15). Various policy and institutional options may facilitate both public and private R&D investment and payoffs as well as alliances among them. These options are discussed below at several levels of decision making—research institutes, national, regional, and global—noting the relevance of each to NARSs' capacity level.

(a) *Options for individual research institutions*

At the level of individual research institutes, the main challenges to accessing technology are priority setting, establishment of international alliances, management of IP, and capacity development.

(i) *Strategy formulation and priority setting*

Many public research institutes have established biotechnology programs that are "tool driven" but without defining a clear strategy and set of priorities. Reviews of program content show that few programs have identified their strategic niche in an often complex national and international market. A key challenge for NARSs is to establish the comparative advantage of the public sector, and identify target populations and priority traits

to meet the mandate of the institution (Hossain *et al*., 2000). Recent examples of priority setting in biotechnology research offer promise to provide more rigor to program formulation (Braunschweig, 2000).

Complementarity with the private sector needs to be a central criteria in priority setting for public research organizations. In the early stages, public sector support is often the key to private sector entry into the market (Pray & Fuglie, 2000). Once the private sector is established, however the public sector is often reluctant to withdraw, and in many cases becomes a competitor. This may be justified under certain conditions to maintain a competitive seed market in a situation of a potential monopoly supplier, but in many cases, such as hybrid seed, the public sector has continued to carry out nonpublic good's research well beyond any justification on these grounds.

(ii) *International alliances*

All public NARSs will have to develop international alliances, both public and private, to access technology. The number of international alliances with the advanced public research institutes in industrialized countries is increasing but these have usually not been driven by priorities of the developing country institute (Cohen, 1999). An exception in this regard is the alliance that EMBRAPA in Brazil has formalized with USDA to facilitate exchange of technology and collaborative research (Lesser, Horstkotte-Wesseler, Lele, & Byerlee, 1999).

Alliances between developing country research institutes and private firms have also been developed but usually for very specific technologies. Most of these alliances have been brokered through intermediary organizations, such as ISAAA. Some NARS have developed alliances bilaterally independently of intermediaries such as the alliance between PhilRice (the public sector rice research organization in the Philippines) and a biotechnology company for genomics research. But, cultural differences between public and private sectors and lack of IP and business management and negotiating skills in public sector-NARSs are major hurdles for these types of alliances.

(iii) *Capacity to negotiate and manage IP*

Most public research institutes in developing countries lack even minimal capacity in IP management. Increasingly, public research institutes will have to develop their own IP policies and management capacity with a combination of legal, business, and technical knowledge consistent with market size and costs (Lesser *et al*., 1999). Policies should clarify institutional roles, identify proprietary technologies, secure ownership of assets, and guide management of IP, technology transfer and marketing of IP (Cohen *et al*., 1999). To become effective, relevant changes in IPR policy must be absorbed into the institutions' internal culture (Sampaio & Brito da Cunha, 1999). This usually requires some type of IPR committee or unit to guide policy formulation and implementation for managing patents on their own IP, and for negotiating contracts and transfer agreements with other research organizations, public or private (Sampaio & Brito da Cunha, 1999). Public sector research systems will also need to develop strategies for determining the profile of IP use and in negotiating a satisfactory arrangement with the various owners in different countries. Finally, an important part of negotiating IP agreements with the private sector will be transparency and accountability to ensure that public organizations are operating in the public interest. [2]

(iv) *Intellectual property policy on own inventions*

While IP issues initially arise in accessing others' technologies, public research institutes with significant biotechnology research capacity, must also establish a policy for protection of their own IP (Barton *et al*., 1999). Cost of IP protection and enforcement will also be a key factor in decision making. Costs will vary enormously from relatively low-cost protection in local markets through plant breeders' rights to expensive patent protection in regional and global markets that requires extensive data searches and multiple patent filing. Experience suggests that income generation should *not* be the primary motivation for IP protection in the public sector, since only a handful of patents earn significant revenues. Rather defensive protection to keep innovations in the public domain and to use them as bargaining chips are likely to be the major reason for IP protection of public sector innovations.

(b) *Options at the country level*

(i) *Development of a national biotechnology strategy*

While many countries are investing in biotechnology, these investments are often very

supply driven and in larger countries, fragmented. In particular, there is often little linkage between agricultural research institutes and general science institutes and universities who conduct much of the research on both agricultural and medical-related biotechnology (Janssen *et al.*, 2000). As a result, public research institutions, even within a country, are not exploiting complementarities and economies of size. There is also a need for better collaboration between biotechnology institutes and those involved in crop breeding to ensure that biotechnology research responds to priority demands, and when tools and products are developed, they are quickly used to improve varieties for farmers. Options for improving synergies include participatory formulation of a national science and technology policy with wide "ownership," as well as establishment of competitive funds that favor proposals based on partnerships of research organizations with complementary skills and assets.

(ii) *Centralized technology transfer offices*

In order to reduce costs, some countries are moving toward centralized national technology transfer and IP services to seek out and negotiate appropriate tools (Maredia, Erbisch, & Sampaio, 2000). A centralized service at the national level can facilitate external negotiations and provide support to institutions that lack the needed skills. Technology transfer offices could also aid in harmonizing MTAs among public organizations in order to reduce transactions costs of transferring IP within a country (Lesser *et al.*, 1999). For example, Indonesia, has established a central office for technology transfer to help negotiate access to technologies of value to Indonesian agricultural research programs. Likewise the CGIAR has recently developed a Central Advisory Service to support the CGIAR centers in developing databases on IPR expertise, patents and IP issues, and assisting them in IP negotiations. Centralization may also provide increased bargaining strength in negotiations on technology access. The main risks of centralization is the distancing of IP management from research decision making and the potential to create another bureaucratic hurdle for scientists.

(iii) *Ensuring an enabling regulatory environment*

An enabling regulatory environment is critical for entry of the private sector and for public sector access to technologies. Most developing countries still do not have adequate biosafety and IPR regulations in place, although most are formulating regulations as required by international treaties. In addition, most countries have rigid and outdated regulations on import of germplasm and release of varieties, based on public sector needs, that are barriers to entry of both local and global private firms. For small countries, costs of establishing adequate analytical capacity for decision making, and cost of enforcing regulations, may be large in relation to benefits. Effective implementation of the recent Cartegena Biosafety Protocol of the Convention on Biological Diversity however will require that all sovereign countries have capacity to make decisions on importation of transgenic products and seeds.

(c) *Options at the regional level*

(i) *Regional research consortia*

Individual public research organizations in small and medium-sized developing countries are at a comparative disadvantage in accessing biotechnology products due to substantial economies of size in biotechnology research, small market size, and their weak bargaining position with respect to large private firms. Public NARSs within a region will often have similar targets, needs and assets and this provides an incentive to pool resources. One approach is to form consortia of public NARSs within a region, or even across regions, in order to access priority biotechnology knowledge, tools and products. [3]

NARSs may be in a better position to gain access and/or cross-license if they negotiate as a consortium or group, and costs can be shared. In some cases, a consortium of strong NARSs could pool resources to "design around" a component proprietary technology. A regional consortium could also form the basis for free sharing of germplasm products and biotechnology tools among public NARSs within a region.

There are thus strong reasons for formalization of regional consortia in biotechnology. Regional collaboration is already occurring through programs such as the Asian Rice Biotechnology Network (ARBN), the Asian Maize Biotechnology Network (AMBIONET) and the Latin American Biotechnology Network, REDBIO. But, to be able to handle sensitive IP issues and negotiate with the private sector,

such networks will need to upgrade to a consortium with a legal basis which may require a strong but small central unit to negotiate and even hold IP on behalf of consortium members. This poses a much greater and as yet untested challenge.

(ii) *Regional regulatory frameworks*

Successful regional cooperation in IPR, biosafety, food safety, variety release regulations and seed laws, would provide a strong basis for private firms to reap economies of size, by operating in larger markets, and also considerably reduce costs of biosafety approval and IP transactions, to both private and public research organizations and to regulatory bodies. One approach used in the EU, is harmonization of member-country regulations combined with a system of reciprocal recognition of plant varietal protection and varietal release, for all countries in a region. Another approach that may be even more cost effective would be to establish centralized regional regulatory offices to serve all member countries in a region. In Africa, for example, regional patent offices allow centralized patent registration. These arrangements will be especially relevant for regions made up of small and medium-sized countries, many of which will be adopting plant varietal rights, and biosafety and food safety rules in the near future. The emerging regional agricultural research associations which are now active in all regions could play a proactive role in facilitating such initiatives.

(d) *Options at the global level*

At the global level, there are a many institutional options for donors and international organizations to facilitate access by developing countries to knowledge, tools, and technologies of high priority to poor producers and consumers.

(i) *Support to the CGIAR*

The CGIAR, although a relatively small investor in biotechnology, is a potentially important "bridge" between advanced private and public research organizations and public research organizations in developing countries, especially smaller NARSs. Each of the crop and livestock CGIAR centers have established a capacity in biotechnology, usually downstream in the R&D chain, but with suboptimal collaboration among them. The recent review of plant breeding and biotechnology in the CGIAR has recommended sharply increased efforts to communicate, collaborate, and share tools and expertise among the CGIAR centers (Technical Advisory Committee, 2000). Given economies of size in biotechnology research and the increase in spillover potential among crops with the application of genomics and bioinformatics, the question arises on whether the CGIAR should be centralizing *the conduct* of some of its biotechnology research either at the global level or at the regional level. Even with centralization, it is not clear what research should be undertaken in the CGIAR, what should be done in partnership with nonCGIAR centers, and what should be contracted out. Another option would be to *centralize funding* of selected activities, perhaps on a competitive basis, at the same time, giving preference to funding partnerships among centers and with others to deliver specific tools and products that have broad applicability.

Much of the technology and many of the tools used in the CGIAR, have been acquired from the private sector. Several CGIAR centers have also negotiated partnerships with the private sector using their own tools and products as bargaining chips. But, the CGIAR centers lacked experience with proprietary technologies and have been "learning on the job." In many cases, formal agreements had not been obtained for research or the commercial use of technologies arising from application of the tools (Cohen *et al.*, 1999). Many CGIAR centers are experimenting with market segmentation approaches, and some have been able to obtain licenses to allow selected countries or regions (and sometimes all developing countries) to freely use the tools and the resulting products. CGIAR centers do not release products directly to farmers, but to NARSs, and various and sometimes complex arrangements are possible for handling of IP. IRRI, for example, has proposed a model for the transfer of IP traits to locally adapted germplasm built around a triangular agreement between IRRI, the IP owner, and the NARSs. The model uses a license or MTA *for research* between IRRI and the IP owner, on the understanding that a NARS that wishes to use products of the research would obtain a license agreement *for use* directly with the IP owner(s) in ways that provide the best choices for its farmers. Similar principles are also being developed for new initiatives in functional genomics, described in

Fischer, Barton, Khush, Leung, and Cantrell (2000).

One major disadvantage of this approach is the cost and skills needed for each NARS to negotiate with the IP owner. Regional consortia and other collaborative arrangements may be a more cost-effective way for NARSs to negotiate such agreements.

Alternatively, where the countries served by the CGIAR center are mainly made up of noncommercial users in type III NARS, it should be possible for the CGIAR center to negotiate the freedom to operate for *research and use* for all countries being served (e.g., for centers operating in Africa).

IP strategies of CGIAR centers will necessarily vary according to the target region and crop. Centers such as IRRI that mostly target strong NARSs where there is a growing private sector presence, will necessarily adopt very different strategies to centers that mostly target weaker NARSs.

(ii) *Global funding through a donor consortia*

New and innovative global approaches to forming partnerships between the private and public research systems for application in developing countries are needed (Pinstrup-Andersen & Cohen, 2000). Although donors allocate considerable resources for biotechnology research for developing countries, this effort is fragmented and does not exploit potential synergies of efforts. One approach to engaging the private sector in developing technologies primarily for use in noncommercial markets, would be for a consortium of donors to establish a fund to competitively contract the private sector to provide high priority technology (Sachs, 1999). The consortium would establish priority tools and technologies and then request bids to develop them, perhaps on a regional basis. Universities and other advanced research organizations in the public sector of the industrialized countries and developing countries also offer much potential to provide priority technologies through such a process. The recipient countries might also be asked to join such alliances and pledge part of the costs of delivering the product to users. Such an arrangement could be especially appropriate to access key enabling technologies for the so-called ''orphaned'' crops. The same fund could also hold the IP of resulting products, which would be freely available in noncommercial markets, but might be licensed for earning royalties in commercial markets.

(iii) *A tool kit for public institutions*

A related proposal would be the formation of a public sector consortium to develop a basic tool kit for the application of biotechnology in developing countries (Fischer, 1999). The consortium would negotiate a license for some components of the tool kit for use by its members. Others components of the tool kit might be ''designed around''—that is, strong NARSs or a consortium of NARSs would invest to develop their own approaches based on nonproprietary technologies or technologies with which they have full freedom to operate. A further extension of this concept would be to encourage a coalition of patent holders to assemble a tool kit to allow one off licensing in order to reduce transactions costs to technology acquisition (Charles Spillane, personal communication).

(iv) *Intellectual property information systems and clearing houses*

A major reasons for market failure in the international transfer of proprietary technology is the high transactions cost of patent search and registration. There is an obvious need for international collaboration to establish IP information systems and clearing houses. Such a system could greatly reduce the cost to developing countries of patent searches both for accessing technology and for patenting their own inventions. CAMBIA, for example, has already established an internet-based patent databases that will enable a user to easily access and analyze published patents and patent applications from many countries (CAMBIA, 2001). Similar databases could be established for public domain technologies in order to make these more readily available in developing countries (Spillane, 2000). These information systems might eventually evolve into clearing houses that offer a ''one-stop'' brokerage services for buying and selling of IP.

6. CONCLUSIONS: STRATEGIES FOR NARS OF DIFFERENT CAPACITIES

Although biotechnology research is concentrated in the ''north,'' research aimed at poor producers and consumers in developing countries is growing, led by the public sector. The total investment of over US$200 million by donors, the CGIAR, and developing country NARSs in agricultural biotechnology is significant and probably several times larger than

private R&D *directed* at developing country farmers (although small in relation to that invested by private companies in industrialized countries).

This review has been framed within the wide variation of NARSs' capacities in biotechnology research and in the characteristics of the markets in which their products will be used. Table 5 summarizes the very different options and strategies for the strong type I NARSs and the large group of type III NARSs that currently have no capacity. Strong NARSs are already moving to develop upstream capacity in tool development and genomics, and potentially these NARSs could become major players in the global market place. Although they need to improve skills in IP management and negotiation, they will be able to make deals directly with private companies to access technologies and for joint ventures, using both their germplasm assets and their own proprietary tools as bargaining chips.

At the other extreme are the large number of relatively weak NARSs with no current capacity. All but the smallest of these countries need to develop a core capacity to seek out, import, evaluate and regulate appropriate technologies from abroad. This core capacity would consist of a nucleus of scientists and policy analysts that can closely monitor developments on the global scene, set a few well-defined priorities for the country, and tap tools

Table 5. *Summary of main policies and strategic options for NARSs of differing capacities*[a]

Issue	Type I NARSs that already have strong biotech capacity	Type III NARSs with no current capacity in molecular biology
Public sector research capacity	—Invest in upstream capacity for tool development, and to design around key components —Contribute to global structural and functional genomics consortia and databases —Define and assert "ownership" of selected biological assests for specific traits	—Develop minimum capacity to seek out, evaluate and regulate appropriate technologies from abroad —Define and assert "ownership" of selected biological assets for specific traits
Private sector research	—Provide favorable regulatory environment on technology importation, protection, and release consistent with societal norms on risks. —Revisit priorities of public sector to ensure complementarity with the private sector	—Provide favorable regulatory environment on technology importation and release, preferably through harmonized or centralized regulations at the regional level, and reciprocal agreements among countries in the region
Public–private partnerships	—Negotiate commercial licensing agreement directly with private companies for accessing tools and technologies for commercial and emerging markets —Bargain for royalty free license for noncompetitive market —Develop and protect own IP products and for use as bargaining chips in joint ventures	—Obtain access to products under royalty-free license, often through intermediaries such as regional consortia and the CGIAR
Regional/international alliances	—Develop partnerships for upstream research with advance public and private research organizations and with the CGIAR	—Promote regional networks and consortia to borrow technologies —Develop alliances with CGIAR, and multilaternal initiatives to act as intermediaries

[a] Type II NARSs who are developing biotech capacity will be intermediate between the two extremes depicted in this table.

and technologies that meet those priorities. This capacity will also be required to meet obligations in recent international treaties. Clearly, these NARSs can gain most by regional approaches both in research capacity and in regulation. They will also need to develop alliances with intermediaries, especially the CGIAR. On the other hand, these countries enjoy a major advantage in exploiting segmented markets to obtain products from the private sector free of royalties, either through negotiation or by unilaterally accessing technologies.

For most NARSs and especially for those which are developing capacity (i.e., type II), innovative mechanisms, such as consortia, are needed to pool public sector resources to buy, develop, and license priority technologies. Many needed tools will be common across crop and geographic boundaries, providing opportunities for consortia or networks to concentrate public resources to solve a common problem. While many networks are moving toward such collaboration, the increasing importance of IP requires that they establish a more formal legal and business base.

For all NARSs, strengthening of their funding and institutional base for public R&D will be critical to address emerging challenges in food security and the environment, and especially to tap global advances in science to address these problems. All NARSs are being challenged to increase investment in biotechnology capacity in a time of stagnating support for public R&D. The public sector must reexamine its targets to ensure that it complements and does not "crowd out" potential commercial markets. For strong NARSs, resources to enhance their capacity in biotechnology can be obtained in part by gradually turning over much of the applied plant breeding in favored environments to the private sector. This requires an appropriate enabling environment for the private R&D, and well-defined strategies and priorities for the public sector. Of particular concern are the large number of relatively weak NARSs with no capacity in molecular biotechnology. For these NARSs, it will be risky to develop a minimal capacity in biotechnology at the expense of other applied research areas, and increased public investment in R&D combined with regional approaches is the only way forward.

Public research organizations have to redefine their role and upgrade their expertise in a changing world of new science, and new norms about the ownership, sharing and use of that science. Public research organizations at different levels—national, regional and international—will have to develop innovative mechanisms to work with the private sector to access needed tools and technologies, recognizing the complementarity among goals, skills, and assets of each side. The public sector has critical assets in the form of germplasm and associated biological knowledge which are increasingly important in the new science of genomics. To fully exploit these assets, however the public sector must develop a capacity in IP management and in business skills, and clearly identify the value of its own assets in the negotiations. Market segmentation is likely to be a key element in public–private negotiations. Although most public–private alliances to date have been based on free access to proprietary technologies for noncompeting markets, this is unlikely to be a sustainable strategy. The public sector realistically needs to think in terms of royalty payments (hopefully discounted) to the private sector in order to maintain a flow of up-to-date and relevant tools and technologies.

Finally at the global level, there are a variety of options for innovative partnerships among donors, multilateral agencies, the private sector, and NARSs to bring fragmented resources to bear to solve priority problems that transcend national and regional boundaries. International leadership is needed to explore the establishment of an international fund to bid for the supply of key enabling technologies of priority for poor consumers and producers. In addition, the formation of global public–private alliances and international agreements will be critical to ensure that the current explosion in genomic information can be tapped to solve problems of poor producers and consumers.

NOTES

1. This is undoubtedly an underestimate because of the considerable spilloves from the much larger investment in pharmaceutical and medical biotechnology research to agricultural biotechnology research.

2. For example, public organizations should be prepared to disclose full details of such agreements.

3. This is especially so, where NARS in a region have similar capacities. But, interests of NARS of different capacities may reduce incentives for regional collaboration, especially since type I NARS are in a strong negotiating position as tool developers, and type III are essentially importers of the technology.

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