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International Agricultural Research as a Global Public Good[1]

A Review of Concepts, Experience, and Policy Issues

Dana G. Dalrymple[2]

Abstract

The concept of Global Public Goods (GPGs) is becoming increasingly important in the international development circles, but little attention has been given to its role in science and technology. Yet one clear example - also overlooked in most of the GPG literature - has existed for 30 years: the Consultative Group on International Agricultural Research (CGIAR). Agricultural research in the poorer developing nations is largely conducted in the public sector and the CGIAR was formed to develop, with these nations, improved technologies and policies for their use in food production. The process has worked well: the CGIAR has, perhaps unwittingly, been a classic provider of GPGs. But public funding for the CGIAR has become tighter and more restricted, threatening to weaken its global scientific capacity. Other global public research efforts, such as proposed in health, could well face similar issues. Greater understanding of the GPG concept as it applies to research, both public and private, is needed at the policy level if these efforts are to be realized and endure.

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[1] An early version of this paper was presented in March 2001 at a symposium sponsored by the International Maize and Wheat Improvement Center (CIMMYT) in Ciudad Obregon, Mexico (Dalrymple, 2002a). A recent companion paper, "Scientific Knowledge as a Global Public Good," was presented at a symposium sponsored by the National Academies of Science in Washington, D. C., September 2002 (Dalrymple, 2002b).

[2] Senior Research Advisor, Office of Agriculture and Food Security, Bureau for Economic Growth, Agriculture and Trade, U.S. Agency for International Development (USAID), Washington, D. C. 20523-2110 [ddalrymple@usaid.gov]; Agricultural Economist, Foreign Agricultural Service, U.S. Department of Agriculture. The views expressed here are my own and not necessarily those of my employers. Helpful review comments, suggestions, and other forms of assistance were provided by a wide and varied group of individuals, now too numerous to list individually (many are authors of publications cited).

The harvest that comes from well-directed and thorough scientific research has no fleeting value, but abides through the years, as the greatest agency for the welfare of mankind.
-*John Wesley Powell*, 1884[3]

Economic growth itself has been largely determined by the capacity to use new technologies, whether developed at home or abroad.
-*Nathan Rosenberg*, 1982

I. Introduction

The proper use of public funds has long been a matter of public concern and debate. Aristotle (384-322 B.C.) wrote in *Politics* of the need for public expenditures and that the most important function of the state is to decide "what is for the public interest…." (Aristotle, 1943; Swanson, 1992).[4] The issue was further defined by Adam Smith (2000) with respect to public institutions and works in *The Wealth of Nations* in 1776.[5]

The debate continues with, if anything, increased fervor today. Although Smith laid the basis for the concept of Public Goods, he did not use the term directly. And while it is regarded as "one of the oldest and most important ideas in the study of public finance" (Olson, 1971), it has taken a long time for the phrase to become a focal point for public discussion. Even where it has, relatively little has been said about the international dimension or science.

This situation has started to change in both the international and scientific arenas. Increasing attention has been given to Global Public Goods (GPGs) by both the United Nations Development Program (UNDP) and the World Bank. UNDP sponsored a book-length collection of papers on the subject in 1999 (Kaul, Grunberg and Stern, 1999a)[6] and the World Bank has recently done the same (Gerard, Ferroni and Mody). The Bank, moreover, has conducted a large study of the activities that it has sponsored that are of a Global Public Good nature (World Bank 2002). Interest has been slower to develop on the scientific side, but has recently been stimulated by the writings of Sachs (1999, 2000a),

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[3] Powell was the first director of the U.S. Geological Survey.

[4] With respect to other functions, he stated: "First there must be food."

[5] Smith stated, famously, as follows: "The third and last duty of the sovereign or commonwealth is that of erecting and maintaining those public institutions and those public works, which, though they may be in the highest degree advantageous to a great society, are, however, of such a nature, that the profit could never repay the expense to any individual or small number of individuals, and for which it therefore cannot be expected that any individual or small number of individuals should erect or maintain."

[6] Unfortunately the volume does not contain a chapter on agriculture and says little about science or research, except as reflected in a chapter on "Knowledge as a Public Good" by Stiglitz. The same is true of a forthcoming volume (titled "Providing Public Goods: Managing Globalization"), again except as partly reflected in a chapter on a related topic: biodiversity.

who highlighted the importance of agricultural and health research for developing nations, and others. The subject was introduced in some presentations (including one by Sachs) and discussions at the October 2000 meeting of the Consultative Group on International Agricultural Research (CGIAR) (Sachs, 2000b; CGIAR, 2000).

These organizations and individuals have realized that many of the important economic and social problems of the developing countries transcend national political boundaries and require a broader approach than is possible in individual country projects or loans. It is less widely recognized, at the public level at least, that a broader approach to research may also provide significant economies of scale, spillovers, and synergetic interactions. These advantages have been understood for some time by those involved in the establishment and operation of the CGIAR, but do not seem to have been given much attention by the broader development community.

The CGIAR is a prime example of the promise, performance, and perils of an international approach to providing global public goods.[7] The group, established in 1972, now sponsors 16 agricultural and natural resource centers that cover a wide range of research activities in and for developing countries. The four major areas of activity include increasing productivity in food production, protecting the environment, saving biodiversity, and improving related policies. CGIAR centers in aggregate also carry the world's largest collection of crop germplasm.[8]

For most of its life, the CGIAR system has not been placed in a International or Global Public Goods context.[9] Therefore, it may be useful to start by outlining the major characteristics of GPSs and show how they relate to or interact with international agricultural research as exemplified by the CGIAR.[10]

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[7] The CGIAR is by no means the only group involved in international agricultural research, but the others are less global in nature and more limited in scope of activity. Further information on these programs is provided in Gryseels and Anderson (1991, 329-335).

[8] A broad array of information on the CGIAR system, individual research centers, research programs, and publications can be readily obtained from the group's web site: [www.cgiar.org].

[9] While the aggregate effect of the CGIAR is global, the individual centers differ in the extent to which they operate globally. Most function to some degree in all four regions of the developing world, but there is a tendency to emphasize one or two regions (such as Africa). Data on expenditures by region are provided in CGIAR (2001).

[10] Perhaps the first person to do so was Winkelmann (1994).

II. Evolution of Concepts

The term Global Public Good appears fairly simple and intuitively appealing, in contrast to some other terms that have their roots in economics, but it is not entirely self explanatory. And its definition has evolved and broadened over time. Systematic formulation of the theory began with Samuelson (1954, 1955) and application to global challenges followed in the 1960s (Kaul, Grunberg and Stern, 1996b).[11]

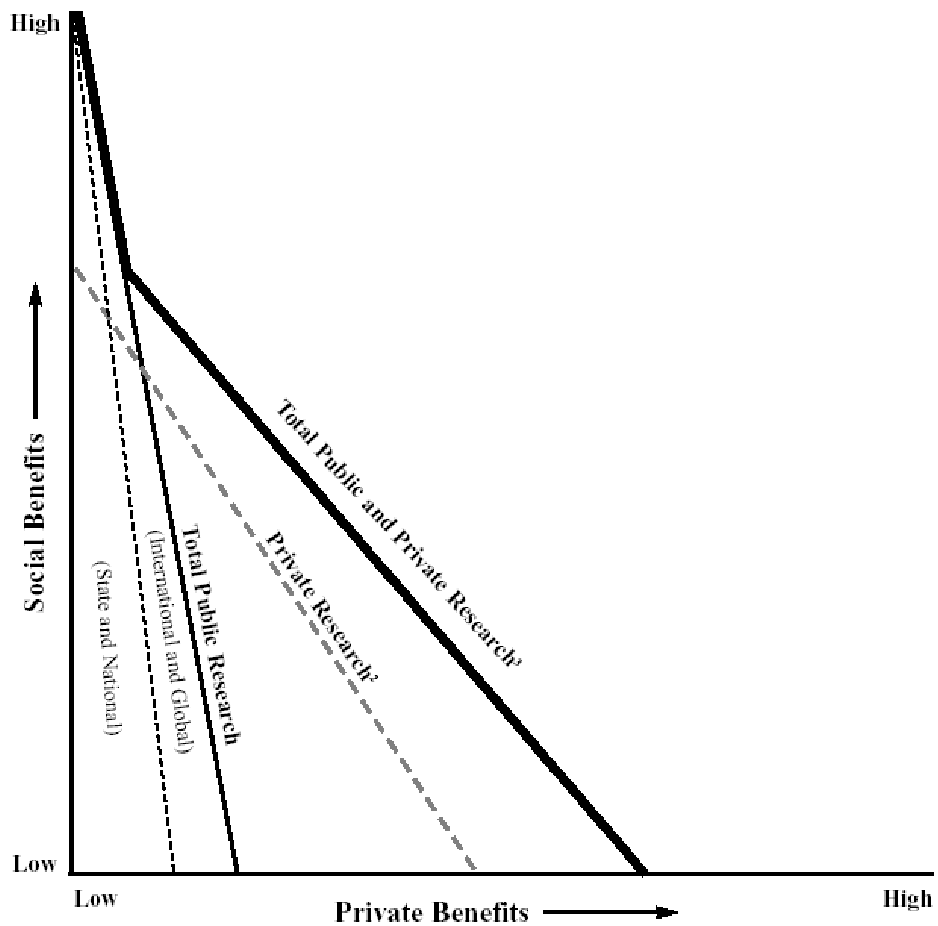
The importance of science in improving the lot of society and stimulating wealth (income) appears to have first been recognized by Bacon in the early 1600s (Henry, 2002; Kealey, 1996; Bacon, 2000). While the classical economists – Smith, Marx and Marshall – were aware of the role of technical advance, the subject was not given much attention until the 1950s (Nelson, 1987), and the appearance of a key article on technical change and the production function by Solow (1957).

Nelson (1959) and Arrow (1962) were the first to argue that the social returns to research investment exceeded the private returns realized by the individual firm and hence that scientific and technical knowledge possesses a public goods dimension (Ruttan, 2001; Mowery and Rosenberg, 1989). Subsequent research supported the theory that social returns from private investment may exceed the private returns (Peterson, 1976; Mansfield, 1977). Thus research programs in both public and private sectors may produce public goods that have social benefits (they may also inadvertently produce some social "bads"). Moreover, there may be a synergistic relationship between the two sectors.[12] These relationships are portrayed in Figure 1.

[11] A standard textbook presentation is provided by Stiglitz (2000).
[12] The importance of the relationship was evidently understood in a more general way by Aristotle who, according to one scholar, thought that "just as the public cannot flourish without the private, so the public needs the private" and that a regime should seek "a dynamic equilibrium between public and private." (Swanson, 1992, 208)

Figure 1

Hypothetical Relationship Between the Social and Private Benefits from Public and Private Research[1]



Notes:

1 The area under the lines represents benefits to the individual components and to society as a whole. The slopes of the lines and the distance between them could vary greatly in individual situations and between developed and developing countries.

2 The private research line is drawn on the assumption that the social returns to private research are larger than the private returns but less than the social returns from public research. This assumption may not hold in all cases.

3 While the cumulative effect as shown here is merely arithmetical here, the interaction and synergy effect between the various types of research should result in a multiplier effect.

Public goods, as generally understood, have two distinct characteristics: (1) they are *freely available to all,* and, (2) they are *not diminished by use*. These properties, are often expressed by economists in terms of rivalness: nonrival (use by one does not limit use by another) or rival (use by one does preclude use by others).

These qualities, in their pure form, are exemplified by knowledge – as was eloquently observed by Powell in 1886: "The learning of one man does not subtract from the learning of another, as if there were a limited quantity to be divided into exclusive holdings…That which one man gains by discovery is a gain of other men. And these multiple gains become invested capital…"[13] So it is – subject to some constraints – with research.

As public goods were originally intended for use within a given set of political boundaries, it was natural that they should be paid for by the government of that political unit, or in combination with the next higher or lower unit (e.g. some combination of national, state, and local government).[14] Public funding was, however, often inadequate, leading to an under-supply problem (this is sometimes referred to as market failure).

Over time, it was increasingly recognized that many important social problems extended beyond the purview of one nation and that a broader approach was needed - involving neighboring nations, sub-regions, regions, and finally the global or world-wide community.[15] In some cases, global public organizations were established, but they generally had little involvement in research and development. Current interest is more strongly driven by health and environmental problems that have science and technology dimensions and which often require further research and development. This has led to more involvement with the private sector. These multiple relationships are illustrated in <u>Figure 2.</u>

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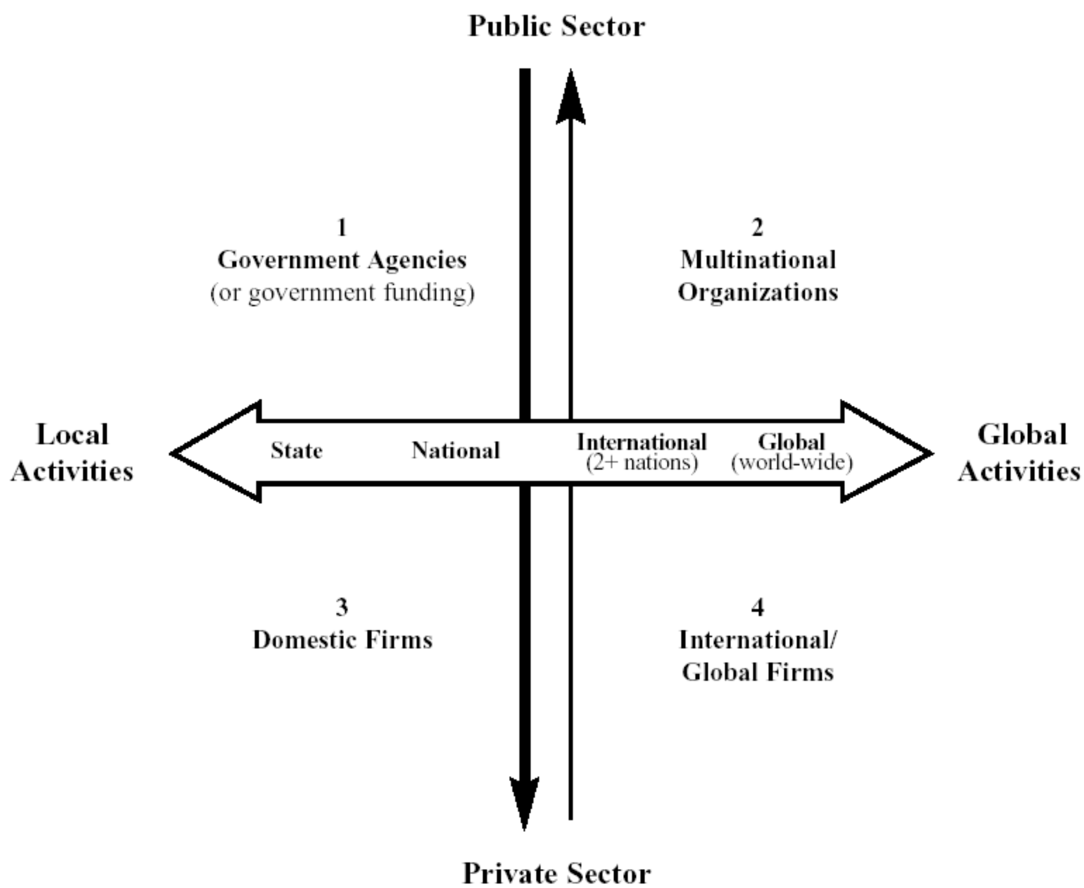
[13] The full text is in Powell (1886). Extracts appear in Ruttan (1991) and Stenger (1992). Jefferson (1984) had previously commented, in 1813, that "He who receives an idea from me, receives instruction himself, without lessening mine; as he who lights his taper at mine receives light without darkening me." A similar view was expressed in a sermon by Augustine between 391-401 (Wills, 1991).

[14] Aristotle (1943) recognized some ordering in the process when he wrote "the state or political community, which is the highest of all, and which embraces all the rest, aims at good in a greater degree than at any other, and at the highest good."

[15] This expansion involved a steadily greater degree of internationalization and leads to the need to draw a seemingly small but important semantic distinction. In formal definitional terms, International may include as few as two nations while Global is defined as being world-wide (*Webster's*). Thus there can be a significant difference in geographic inclusiveness. The two words, however, are often used interchangeably, as is the case within the CGIAR system. A further definitional complication, which becomes more important in the case of research, is that basically the same good might be considered National in a larger country context and International within a group of smaller nations; the distinction may be drawn on the basis of political boundary rather than the nature of the good itself.

Figure 2

Relationship of Public and Private Sectors of Varying Geographic Scope in Provision of Science-Based Goods

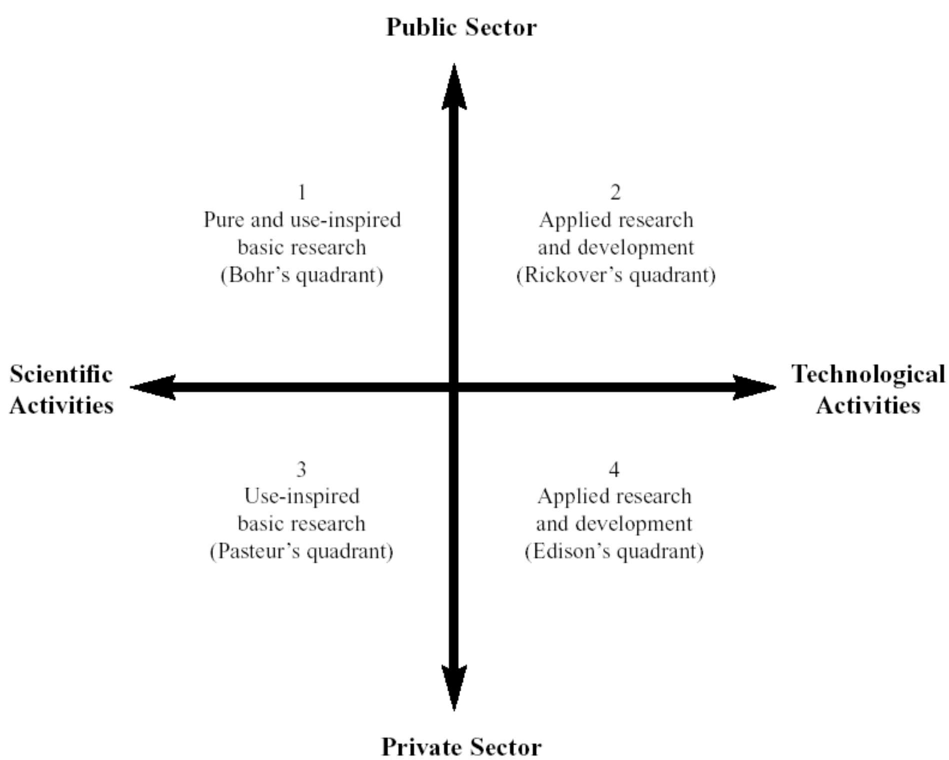


Note: It is assumed that each quadrant interacts with each other, although it is recognized that traditionally the private sector has drawn more from the public sector than vice versa. The degree to which this is true, however, is changing as the private sector becomes more important in some areas of scientific research and has an increasing hold on intellectual property rights.

In formal terms, any goods which are not purely public or private are considered impure public goods (Cornes and Sandler, 1996). But as David (2002) has written: “The term ‘public good’ does not imply that such commodities cannot be privately supplied, nor does it mean that the government must produce it.” Indeed, he continues: “A well-functioning science and technology system requires getting the correct balance and maintaining active communications between these two quite different types of organizations, because the special capabilities of each are required to sustain the pace of economic innovation and economic growth over the longer term." Moreover, he sees both types as needed to permit society to respond to a variety of problems - "challenges whose solution will call for the creation of more effective modes of international scientific and engineering collaboration."[16] The generalized relationships between these groups are depicted in Figure 3.

Figure 3

Quadrant Model of Organization of Public and Private Scientific Research and Technology Development



Source: Adapted from Vernon W. Ruttan, *Technology, Growth, and Development: An Induced Innovation Perspective,* Oxford University Press, 2001, p. 537 (in turn partly adapted from Donald E. Stokes, *Pasteur's Quadrant; Basic Science and Technological Innovation*, Brookings Institution Press, 1997, p. 73).

Notes: The quadrants are not self-contained: it is assumed that there would be interaction between each. In Stokes' original conception, Bohr's quadrant was limited to pure basic research and did not distinguish between the public and private sectors. Use-inspired public basic research is typified by the National Institutes of Health in the U.S. (Stokes, pp. 137-142).

[16] On the other hand, there may be situations where the two sectors compete or displace each other (see, for example, de Gorter and Zilberman, 1990).

Thus it is easy to see how public international agricultural (and associated natural resource) research[17] fits readily into an International or Global Public Goods framework. According to the GPG classification system developed by Sandler, it would fall in the "Best Shot" category. This group involves a *concerted approach* depending on *focused technical expertise*, which benefits from *economies of scale*, and which is organized for production and delivery in a "*mission-oriented manner*".[18] This is a remarkably apt characterization of the CGIAR System.

III. Organizational and Funding Dimensions

Global Public Goods (or International Public Goods relevant to many nations) of the type produced by the CGIAR System are, as depicted in Figure 2, at one end of the Public Goods spectrum and fit in quadrant 2. They also fit in quadrant 2 of Figure 3, applied research and development. GPGs should, by definition, be of value to a very large number of people around the developing world. But they are also beyond the reach of many international organizations that have been set up for other purposes and generally have a fairly limited science/technology and research/development component. They may also be beyond the reach of many individual bilateral assistance agencies. Thus, the provision of GPGs of this nature represents significant organizational and funding challenges (see Sagasti and Bezanson, 2001).

A. Establishment of the CGIAR. The CGIAR, the first specialized group of its type, was particularly fortunate in its origins. It built on the early success of two research centers, IRRI (the International Rice Research Institute) and the International Maize and Wheat Improvement Center (CIMMYT), which were established by the Rockefeller and Ford Foundations. The foundations had a long history of experience in science and agricultural research (Rockefeller) and international agricultural development (Ford). Moreover, the time was ripe: it was a period of concern about world food shortage and a time when many bilateral donors had a strong interest in agriculture and funding to back up this interest. The establishment of the CGIAR benefited from excellent leadership, in part provided by the World Bank, the two foundations, the co-sponsors the Food and Agriculture Organization of the United Nations (FAO) and UNDP, and some of the donor nations. As a result, the process took only about two years (from 1969 to 1971).[19] An

[17] The role of public agricultural research in international development has been reviewed elsewhere (Dalrymple, 2000).

[18] For further discussion of this category, see: Kanbur and Sandler, with Morrison (1999); Kaul, Grunberg, and Stern (1999).

[19] By comparison, over fifty years elapsed between the first international conference on cholera in 1851 and the establishment of the International Office of Public Hygiene in 1903, and another 44 years to establish the World Health Organization despite clear benefits to all countries from conttrolling the spread of disease (Cooper, 1985; Kindelberger, 1986; Ruttan, 1996).

independent Technical Advisory Committee (TAC) was included from the start (Baum, 1986). In addition, bilateral donors were providing strong support for the development of national research institutions that complemented the global effort of the centers. It was an almost providential alignment of global circumstances, organizations, and structure.

During the subsequent years, additional donors and centers joined the CGIAR. Yet the CGIAR system has a relatively small budget ($337.3 million in 2001) and represents only a small proportion of all public funding for agricultural research in developing nations (an average of only 2.8% over the 1994-96 period[20]). As of 2001 there were 54 donors, including 21 developed (industrialized) nations, 19 developing nations, 3 private foundations, and 11 regional and international organizations. The relative proportion of funding provided by each group was: developed 66.7%, developing 4.0%, foundations 2.7%, international and regional 19.7%, and other 6.9%. The three leading donors were: United States 13.5%, the World Bank 13.3%, and Japan 8.7%; together, they accounted for 35.5% of the total. Part of the World Bank is used to cover the administrative cost of the organization. The Bank also provides the Chairman and houses the CGIAR Secretariat (the TAC Secretariat is housed with FAO in Rome).[21]

While the term GPG was not mentioned in the early years of the CGIAR, the concept did play a subsequent role in the thinking of its Technical Advisory Committee. In a 1990 report it stated that: "In planning and determining priorities in international research, consideration will be give to the maximization of spillover effects that will result from research activities. Over the longer term, supranational rationalization of a good deal of research is a logical goal, with significant savings for participating partner nations." (TAC, 1990).

B. Funding of GPGs. More recently, the GPG concept has moved into the lexicon and funding programs of the donor community. The editors of the recent overview sponsored by UNDP estimated that "…one aid dollar in four supports global public goods rather than just the purely national concerns of poor countries." (Kaul, Grunberg, and Stern, 1999).

Some more detailed data on funding have been compiled by the World Bank (2001). The report distinguishes between *core* activities designed to produce international Public

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[20] Estimate provided by Phil Pardey, IFPRI, May 31, 2001. This figure represented a decline from previous estimates of 3.3% in 1976 and 3.8% for the 1984-86 period. A figure of less than five percent is commonly used. The ratio in terms of researchers is much lower: about 0.4% according to one estimate (Anderson, 1997). Public funding accounted for nearly 95% of all agricultural R&D investments in deveveloping nations in the mid-1960s (Pardey and Bientema, 2001).

[21] The statistical data reported here were derived from CGIAR (2002). The relationship of the Bank to the CGIAR is described in some detail in Anderson and Dalrymple (1999). The Bank's CGIAR contribution represents an uncomfortably large proportion of its limited grant funds which are derived from earnings and are under increasing pressure from several directions (see Kapur, 2002)

Goods (IPGs) and *complementary* activities (concessional loans) which help countries to consume them, in the process creating valuable National Public Goods (NPGs). *Core* Activities include both (i) global-regional programs with a transnational or multi-country interest in mind, and (ii) country-based activities that generate transnational benefits. International agricultural research is considered an example of the first core group. IPGs are divided into five categories: health, environment, knowledge, peace and security, and financial stability. Knowledge is basically composed of research activities and institutions; research is also a component of the health and environment sectors.

The study then examines trends in funding from the 1970s to the late 1990s for country-based official assistance (ODA) (grants and concessional loans). Overall, it appeared that a growing proportion of development assistance was allocated to IPGs. In the late 1990s, core represented about 3.5% of the total and concessional about 15%. In the case of *core* programs, which represented about $2 billion in the late 1990s, funding for health, the environment, and peace keeping grew significantly while funding for knowledge generation and dissemination stagnated. In the case of *concessional* programs, funding totaled about $8 billion: health was the most important and increased substantially; knowledge was second but declined during the 1990s. The report found that spending on knowledge has been "sluggish, with complementary spending on educational facilities and training severely curtailed." And, more specifically, "core spending on agricultural and livestock research has been stagnant." Global-regional programs "attracted only limited attention."

The data clearly indicate that the growth has not taken place in agriculture but in other categories, particularly in health – which is likely to rise even more.[22] Research is clearly an omnipresent component of the World Bank classification of public goods, but its definition is unclear. Further elaboration may be useful.

IV. Characteristics of Research

Research may generally be viewed as the organized and systematic search for new knowledge and improved ways of doing things. An element of discovery is involved. Research is usually intertwined with science, and in many cases they are considered synonymous. Science is, however, often somewhat more narrowly defined: as that branch of knowledge dealing with natural phenomena. And in this case, as Callon (1994) notes, "If we want to grasp the real economic significance of science, we need to recognize it as a source of variety…It causes new states of the world to proliferate."[23]

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[22] The Commission on Macroeconomics and Health, headed by Jeffrey Sachs, presented a report to the World Health Organization in December 2001 recommending spending $3 *billion* a year on research and development for the diseases of the poor by 2007, half through a new Global Health Research Fund and half through existing channels (WHO, 2001).

[23] This topic is discussed more fully in Dalrymple (2002b).

In terms of potential scope of use, Bacon (2000) commented in 1620 that "…the benefits of discoveries may extend to the whole human race." Science, as a form of knowledge, is more likely to inherently be a global public good than is technology, which involves adaptation to particular circumstances and needs. Thus scientific discovery may have a greater degree of "spillover" than technology.[24] Also, science may be more amenable to centralization than technology. But in either case, it is necessary to have adequate adaptive research and development capacity in recipient organizations and nations.[25]

This leads to two key issues: (1) *the economics of size in research*; and (2) *the factors influencing spillovers and spillins*. The first area appears to have received relatively little study, and early work was largely based simply on size of the research enterprise and the firm.[26] The second has been the subject of somewhat greater attention. Both are interrelated. Some particularly useful work on both has been sponsored by, or done by, CIMMYT economists.[27] Byerlee and Traxler suggest that *economies of size in research* are more apt to be found in areas such as chemistry, molecular biology, and genomics, which require a substantial fixed investment in laboratory infrastructure. On the other hand, economies of size are likely to be lowest for crop and resource management, which are more likely to involve field work and adaptation to local environmental conditions (Byerlee and Traxler, 2001). Traditional plant breeding and some forms of livestock research might fall in between.[28] More generally, research with substantial economies of scale is more apt to be accompanied by the potential for higher *spillovers* than research with lower economies of scale. In fact, it may have to have high spillovers to pay for itself in a social sense. These relationships are depicted graphically in Figure 4.[29]

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[24] Even so, as Mokyr (1990) has observed: "modern science has made inventions more universal…by providing insight into the mechanism behind the invention."

[25] Rosenberg (1982) has commented on this issue in a general historical context. Also see: Mowery and Rosenberg, (1989); Geroski (1995); and Russett and Sullivan (1971).

[26] The idea that there are increasing returns in R&D both with respect to size of research establishment and the firm is a derivative of Schumpeter's (1940) views on the efficiency on large scale firms. In any case, the hypothesis is difficult to prove and it has been argued that early tests were inappropriate (Fisher and Temin, 1973).

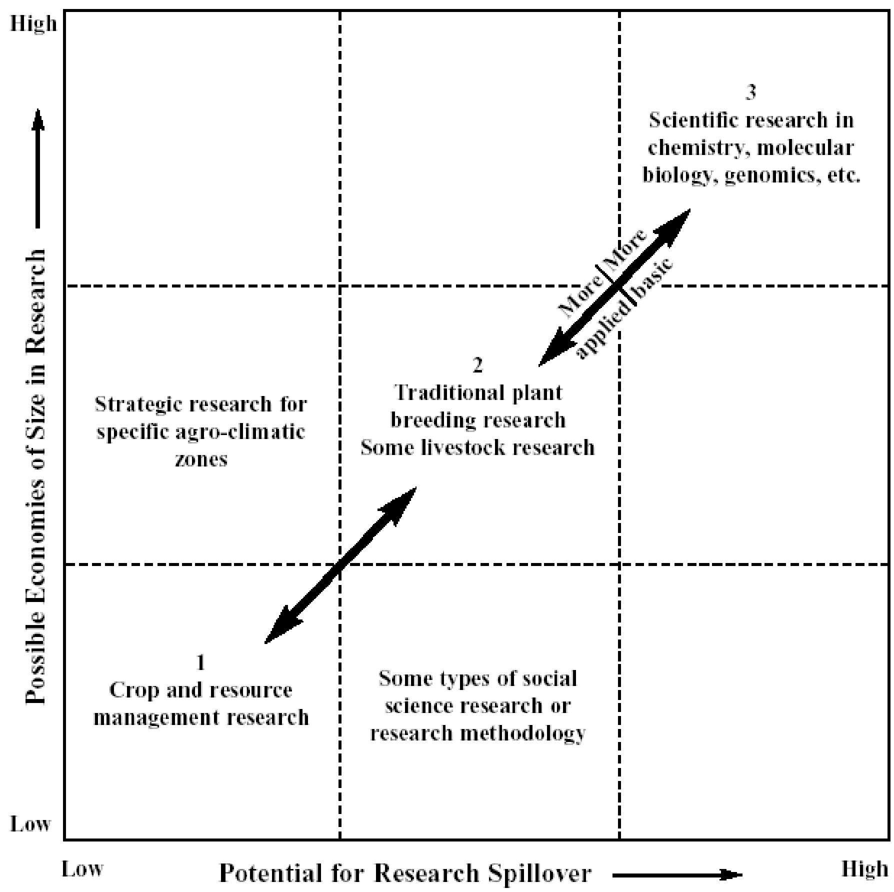
[27] Much of this work is summarized in Mareida and Byerlee (1999). Also see the section on "International Spillovers in Agricultural Research", in Fuglie and Schimmelpfenning (2000).

[28] The overall cost situation is a little more complicated because it needs to take into account two other types of expenditures: (1) the overhead cost of maintaining facilities, no matter the level of use; and (2) the variable costs of carrying out research. The variable costs of some forms of field work, for instance –such as multi-location trials or systems research – can be quite high.

[29] Some other useful diagrammatic approaches to classification are provided by Barnes (2001).

Figure 4

Illustrative Categorization of Agricultural Research Activities in Terms of Possible Economies of Size and Spillover Potential



Source: Adapted from Derek Byerlee and Greg Traxler, "The Role of Technology Spillovers and Economics of Size in the Efficient Design of Agricultural Research Systems", in J.M. Alston, P.G. Pardey, and M.J. Taylor (eds), *Agricultural Science Policy: Changing Global Agendas,* Johns Hopkins University Press, 2001, p. 169, Figure 9.2.

Notes: Biotechnology, depending on the degree to which it is basic or applied, might fall between boxes 2 and 3 or in box 3. Some forms of strategic research for agro-climatic zones might fall in box 2.

Byerlee and Traxler go on to consider another important factor: (3) *market size,* or *economies of scale in technology use*. This might be conceptually viewed as a variant of the two previous variables, or as a third dimension. In its simplest form, it means that the more widely a technology is adopted, the more significant the payoff from the research. This clearly has been the case for public breeding programs for wheat and rice which tend to be raised in similar agro-ecological zones (often irrigated) over wide areas of the world. And it has been facilitated where the centers breed for broad adaptability. Where this is the case, market size can become the dominant determinant of research efficiency.

But there is more to the process. This comes about when it is possible to develop a feed-back loop with users of the technology at the country level. The combination of being able to tap into advanced research in developed countries, to draw on centralized genebanks at headquarters, and interact with a large group of collaborators at the country level adds a further and very significant note of efficiency for the whole process. As Anderson (1998) has noted, the importance of international agricultural research derives in part from "the productivity-boosting collegiality and cost-cutting benefits thereof of sharing information and materials."[30] These complementary two-way relationships between the contributors to the public goods sector (as reflected in the horizontal relationships suggested in Figure 2) may be of major importance in stimulating research productivity.[31]

V. Public-Private Research Relationships[32]

We have noted that, in Callon's (1994) words: "…public and private research are complementary despite being distinct: each draws on the other." There are, however, some increasingly important factors that influence the nature of relationships between the two sectors. This is perhaps most immediately seen in the case of intellectual property rights (IPR). We have also suggested that scientific research (and to some extent technological research) is inherently a public good. Hence, private firms engaging in such research and wishing to keep it from becoming a public good, at least for a while, make use of IPR. The public sector may also make use of IPR protection, but often, paradoxically, for a different reason – to protect the good in order to keep it in the public sector. There may be tension between the public and private sectors in these respects but there also may be cooperative arrangements such as licensing and others.

The two sectors may have some other similarities. Large, multilateral firms, for instance, have the financial resources to carry our centralized research that is verified and adapted in field trials elsewhere. The ability to market in more than one country is every bit as important for the private sector, and to the extent that this occurs, it might be said that they are providing global *private* goods. These goods, which may embody a significant amount of scientific and technical knowledge, can be of considerable importance to recipient nations (see: Coe and Helpman, 1995; Pray and Fuglie, 2001; and Roseboom, 2002a).

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[30] This process might also help identify problems whose solution would help expand the market.

[31] It has been suggested that "R&D not only generates new information, but also enhances the firm's ability to assimilate and exploit existing information" (Cohen and Levinthal, 1989).

[32] For further discussion of this topic, see Byerlee and Echeverria, Eds. (2002) and Dalrymple (2002b).

Both sectors, however, may face somewhat different combinations of problems in achieving these aims. The public sector increasingly has difficulties with funding and intellectual property rights. The private sector may not have as many complications in these areas, but may face other formal or informal barriers to entry in some nations (Gisselquist and Grether, 2000; Tripp and Pal, 2001). In this case, the public system may benefit from its contacts with national systems and be able to transcend national boundaries. The private sector may reach more into the commercial sector of the farming community and the public sector into the lower income portion. Both may face complications associated with government regulations and /or public resistance to genetic engineering, but so far these have been greater problems for the private sector, in part because of the nature of its products. However, the prospect that some public goods might become "regulated public goods" is in sight. (I have attempted to summarize these relationships in graphic form in the Annex.)

In the best of circumstance the two groups can complement each other in important ways. First, public sector research, such as in plant breeding, has long been made available to the private sector: inbred maize lines developed by CIMMYT are widely utilized by the private sector in developing hybrids. Second, the private sector may make technologies or products available for use in developing countries where there is little prospect for a significant commercial market. They may, however, have some strings attached, and require further development and testing by public research organizations. Third, joint public-private collaborative research, some of it rather basic, may be conducted. Some efforts may, of course, be stimulated by public relations considerations.[33]

There is one other important category of participants in the research process: foundations and private philanthropy. These groups have made substantial increases in their overall funding for research (Cohen, 1999). Rockefeller continues its interest in biological research, and has played a vital role. Ford has largely moved to the social science side. New actors have come on the scene but so far have shown little interest in research in food, agriculture and natural resources. Still, they have come close, especially the immense investment made by the Gates Foundation in health to correct a huge "market failure" on the research side (Strouse, 2000; Anonymous, 2001; Cohen, 2002).[34] Similarly, the donor of $100 million to Johns Hopkins University for research on malaria wanted to "…make a real difference in the world" (Argetsinger, 2001).

[33] For some recent accounts relating to both the rice genome and other crop improvement activities, see: Gillis (2002a, 2002b), and Wade (2002).

[34] One article goes on to state: "The world's governments were unwilling to bear the risk of investing in research that might not pay off for 20 years, if at all" (Anonymous, 2001).

VI. CGIAR Policy Issues

Operating an international organization devoted to the production of International or Global Public Goods is a very complex process. It necessarily involves some thorny policy issues and questions. In the case of the CGIAR, some of these have been geopolitical in nature, but others are more closely related to the nature of donor organizations and the research process. Consequently, while the CGIAR is in many ways a prime example of a public goods provider, it faces continual constraints in maintaining both a global perspective and sufficient longer-term research.

As an applied research organization, the CGIAR tries to respond to emerging needs. Perceptions of these needs may vary among donors and the other system components and they may change more quickly than the research process itself. This can lead to tensions and compromises, but can also be offset by the wide range of activities carried out in the System. Often it is able to respond directly to some immediate need by drawing from ongoing center programs or genetic resources. And certain issues may be addressed by the indirect effects of longer-term research. There are, however, limits to this process and further complexities. These will be illustrated in five sets of policy issues.

A. Time, Geography, and Indirect Effects. Consider two categories of examples from the past decade: natural resources and poverty alleviation. In the case of *natural resources*, the CGIAR has taken some obvious moves to expand its work in this area, most notably by setting up or adopting four centers that deal directly with forestry, agroforestry, water management, and fisheries Other centers deal with some of them as components of their programs. This type of work is generally long-term and regional in nature and is fairly difficult to assess the payoff in terms of global benefits.

One example is the adoption of the concept of an ecoregional approach to natural resources. In theory this makes sense: it should be possible to develop technologies that would spill over from one ecoregional zone to another (see McCalla, 1994). Some ecoregional projects were initiated about a decade ago, and eight system-wide programs were reviewed by the Technical Advisory Committee (TAC) of the CGIAR in the late 1990s. It has always been difficult to determine how much spillover from zone to zone has been achieved. Significantly, one of the recommendations of the TAC study (Henzell, Byerlee and Mateo, 2000) is that research should be organized around "major problems…that are of international relevance" and that "…it should provide for its progress to be measured against specific performance indicators." What is not mentioned in the TAC report is that in some cases these programs came with a stiff opportunity cost within the center: in some cases breeding programs, which generally rank well in terms of spillovers, were shrunk to pay for them.[35]

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[35] For example, from 1992-93 to 1998-99, the proportion of the overall CGIAR budget spent on germplasm

This leads to the question of the effect of more general productivity-enhancing technological change in agriculture on natural resources. Both negative and positive effects could be envisaged. A recent review of 140 economic studies of deforestation suggested that the immediate effect of technological change was indeterminate but that the indirect effects generally were positive in that they reduced deforestation (Angelsen and Kaimowitz, 1999; Angelson and Kaimowitz, 2001). Another approach is to estimate the effect of increasing crop productivity on reducing the land area needed to produce these crops and thus saving marginal and forested land from the plow. Recent reviews suggest land saving figures in the 200 million ha (nearly 500 million acres) range, clearly significant figures.[36]

More recently, *poverty alleviation* has become a central theme in the development community. Somewhat the same pattern has emerged: an admirable goal with global potential but one that has tended to be looked at in sub-regional or local terms - tasks which should be carried out by national or regional programs. These could divert the CGIAR away from its comparative advantages in terms of economies of size in research, spillover potential, and economies of market size. It could be deflected into filling gaps arising from shortfalls in national programs. And as in the case of natural resources, the CGIAR is already making major, but sometimes little known, contributions to poverty alleviation by increasing productivity - thereby expanding the supply of staple food crops and lowering food prices for the poor who spend a large portion of their incomes on food. There are also positive spin-off economic effects for early adopters of new technologies, for local employment, and for local communities.

A recent report on poverty prepared under the auspices of the International Fund for Agricultural Development (IFAD, 2001) states that "The anti-poverty record of the Green Revolution was excellent." It goes on, however, to note that "From 1980 the CGIAR moved away from breeding for yield, especially yield potential, towards such issues as environment, gender and distribution, and towards less promising crops and areas. Yet this has probably helped to reduce the growth in the yield of staples even for lead areas of the Green Revolution, and has been ineffective in delivering growth to some of the areas where the poor are increasingly concentrated." "*Research must now be refocused on yield*."[37]

B. Funding Considerations. This is an area where donor actions can have unintended consequences. One has been an accelerating shift from Unrestricted (institutional) financial support to Restricted (targeted) support. Unrestricted funding supports the basic

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enhancement and breeding dropped from 25.25% to 17.70% (CGIAR, 1994-2000).

[36] See, for example: Victor and Ausubel (2000); and Nelson and Maredia (2000). There may be some offsetting negative consequences, such as salinization, but it is difficult to sort out the specific impacts of agricultural research from the effects of more general intensification (Maredia and Pingali, 2001).

[37] Italics added. Also see Byerlee (2000).

longer-term research operations of the centers, including genebanks. The Restricted category is usually for more specific programs or projects that may be shorter term, more localized, and more applied in nature. Although the level of Unrestricted funding held relatively level in dollar terms from 1994 to 1998, it declined rather sharply from 1998 to 2001 (a drop of $60.4 million or 29.3% over the three years). Further, the Unrestricted proportion of total funding dropped from 60.6% in 1998 to 43.1% in 2001 (compiled from CGIAR, 1994-2000; CGIAR, 2002).[38]

If this process continues, as seems likely, it could (depending on the nature of the earmarking) result in a further decline in the funding which is readily available for the "heartland" research activities of the centers.[39] This in turn could well lead to an imbalance in the nature of the scientific work of the system and lessen its Global dimension. There are also less obvious transactions costs in terms of scientist time diverted to securing and reporting on restricted projects.[40] Since the special strength or comparative advantage of the CGIAR is at the Global level, this shift is a matter of some concern and needs to be examined more closely.[41]

A somewhat different funding question relates to the degree to which the costs of research should be borne by the beneficiary countries. The problem here is that the primary intended beneficiaries are the poor nations who by definition are in the weakest position to pay. One early view in the CGIAR was that if these countries could muster some additional funding for research, they should spend it on their own national programs, which in turn would facilitate their ability to utilize GPGs. And though a number of developing countries have joined the CGIAR in recent years, generally with fairly modest contributions, their funding is almost always though the ministries of agriculture and they are represented by that agency. Hence a domestic opportunity cost may be involved. On the other hand, it might be argued that some of the larger counties that have benefited the most from the CGIAR should contribute more, or that a greater portion of the cost of

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[38] It is sometimes difficult to draw a sharp line between the two categories, especially when the restrictions or targeting are very mild or essentially involve placing a country flag on an existing center program.

[39] Not all donor restrictions fall into this category. For example, USAID has a very light earmark, not in the R/T category, calling for 8% of its funding to be used for scientific collaboration with U.S. universities (and through them with other U.S. research institutions); the centers select the institutions and topics. The program has been very well received by both sides and appears to be quite successful. The French have long provided part of their contribution on an in-kind basis in the form of scientists stationed at the centers who have worked on advanced subjects such as apomixis. There may be other such cases.

[40] Some of these issues have been pursued at length in the debates about formula vs. competitive funding of domestic agricultural research in the United States. See, for example: Alston and Pardey (1996), and Huffman and Just (2000).

[41] The shift may partly reflect the desire of some donors for more specific program accountability. From the organizational point of view, the process might be viewed as a variant of (1) the fallacy of composition, whereby what seems good from an individual point of view may not be good for the group (see Hardin, 1982), or (2) of the classic problem of maintaining the commons (see Hardin, 1968). One might also wonder if is sometimes more of a risk-minimizing strategy (in terms of maintaining funding within the donor organization) than an effort to maximize social returns on investment.

regional programs should be carried locally.[42] Another dimension is the secondary benefits that have accrued to at least some of the donor nations. This has been particularly true of the United States in the case of wheat and rice. The benefits to both sets of nations have recently been studied in some detail.[43]

C. Balancing Large and Small Countries. This is a more complex matter than might seem apparent at first. On one hand, small nations may in general have greater need for international or global research than larger nations who are able to carry out a wider range of research activities within their borders. On the other hand, the larger nations may make wider use of international or global research, raising its public goods value. Hence determining the social value of a GPG is not merely a matter of counting countries. A technology that is widely adopted in a large country such as China or India may, because of their comparable populations, have considerably more overall social value than a technology that is adopted in a larger number of smaller countries.

A related issue that has come up in the CGIAR is the degree to which its centers should assist larger countries when they represent the bulk of production and have relatively well developed national research programs (pigeon peas in India and sweet potatoes in China have been recurrent issues). In some cases this is an easy call; in others it is more difficult. The easy call arises when a center is able to make a specific contribution to a large country where it has the potential for widespread impact, at relatively low cost to the center. This happened recently when the International Potato Center (CIP) was able to assist China to adapt a simple and low cost procedure to eliminate viruses.[44]

Moreover, in any large system in a poor country (as well as perhaps elsewhere) there are components that may not have been well supported, have been isolated from the mainstream of science, or have had limited access to GPGs and which could benefit from contact with an outside center. The more difficult task is to assess the tradeoffs and to know where to draw the line.

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[42] Adam Smith (2000) wrote in 1776 that: "Even those public works which are of such a nature that they cannot afford the revenue for maintaining themselves, but of which the conveniency is nearly confined to some particular place or district, are always better maintained by a local or provincial revenue, under the management of a local and provincial administration, than by the general revenue of the state, of which the executive power must always have the management."

[43] The benefits of improved crop varieties to developing nations are reported in Evenson and Gollin (2001 and 2002)) and a more specific analysis of wheat is provided in Heisey, Lantican, and Dubin (2002). A study on the benefits to both developing and selected developed nations has been underway at the International Food Policy Research Institute (IFPRI) for some time and it is hoped to complete a manuscript by the end of 2002.

[44] The process was initially adopted in two provinces on 800,000 ha. (2 million acres) and could be extended to all regions in the country (K.O. Fuglie, et al., 1999; CIP press release, February 13, 2001, [http://www.futureharvest.org]).

Thus the reach to develop *Global* public goods should not obscure the potential for equally large social gains through more limited efforts, in terms of number of countries, where the opportunity for a low cost targeted contribution and/or widespread use is great. This dimension has received some attention by TAC (2000) but merits further thought.

D. Public-Private Sector Issues. There is some question about the degree to which the nature of the demand for agricultural GPGs may change because of: (1) increased research activity by the private sector, (2) increased use of intellectual property rights (IPRs), and (3) increased constraints on the international exchange of plant germplasm.

In the *first* case, the answer depends on what sector of the market is being considered. Barton and Berger (2001) echo the view of many in suggesting that "…the private sector seeds will probably be developed only for the larger commercial markets: it will be a long time before the private sector improves small crops or serves subsistence farmers." The private sector is clearly most interested in hybrid seeds that can be patented; in some cases, however, these are basic food crops (Pray, et al., 1991; Hassan, et al., 2001; and Gerpacio, 2001). Moreover, the public sector research programs are a source of parent materials that can be finished off and sold by local seed companies, many of which have limited research resources and capacity (Dalrymple and Srivastava, 1994; Hassan, et al., 2001; and Heisey, et al., 2001).

Increasing complications associated with the *second* and *third* points seem a more likely and serious possibility over time. Indeed, Barton and Berger (2001) conclude that "For the public sector's research, so critical to the developing world and the future of the human food supply, the patent system is causing enormous complexity and may be slowing the development of needed technology." Further study would be desirable.[45]

These factors could influence the balance of activities within the public sector. If the private sector moves more into genetic improvement in the future, should the public sector redirect more of its activities into crop management or natural resources which are less likely to draw private sector investment?[46] The problem for the CGIAR is that genetic improvement is the area where the greatest GPG benefits can be demonstrated, in contrast to the other two areas where spillovers are apt to be less (Figure 4) and benefits of an even longer-term nature are much more difficult to measure.

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[45] The International Plant Genetic Resources Institute (IPGRI) is initiating a review of "Rights and Responsibilities over Genetic Resources: The Role of the Public Domain in Producing International Public Goods." The point has been further developed with respect to developing countries by a Commission on Intellectual Property Rights headed by John Barton (Commission 2002). Useful background is found in Falcon (2002). Also see Dalrymple (2002b).

[46] Herdt (2001) has advocated that the CGIAR devote more attention to crop management research as well as to "…focusing plant breeding on developing specific traits valuable for regions and crops the private sector neglects." The CGIAR does considerable research for neglected areas and could do more if donors were willing to provide the funding.

This illustrates a basic quandary faced by public sector research. If it is to continue to attract financial support, it must, like the private sector, have a sufficient number of research programs with clear and demonstrable payoffs to offset the usual "dry wells". But it also needs to support other socially important programs with less visible returns. Thus it may be more difficult to show positive overall returns on investment.

One further issue concerns relative short- and long-term impacts. A study of agricultural research in the U.S. from 1951 to l983 found that private research had a larger impact in the short run and that public research had a larger impact in the longer run (Chavas, Aber and Cox, 1997).[47] Whether the same relationship would be found for a more recent period, given the changing nature of research, especially the increasing emphasis on biotechnology, is uncertain.

E. Proposal for Global Challenge Programs. In 2000, the CGIAR decided to initiate a program of change. Two of the major challengeswere "Maintaining science and research at the Centers at the highest levels" and "Strengthening the CGIAR's position as a producer of global public goods"(CGIAR, 2000). Two key proposals reported to the group in 2001 were: (1) the establishment of Global Challege Programs (GCPs) along side of the regular research activities of the Centers; and (2) the transformation of the Technical Advisory Committee (TAC) into a Science Council. The basic idea was to facilitate the CGIAR's ability to take on major global challenges with a wider range of partners and widen the provision of scientific knowledge. "The impact, significance, and visibility of the CGIAR research agenda could be substantially elevated and the CGIAR's own meetings could increasingly focus on higher-level strategic issues…" (CGIAR, 2001). Together, the two proposals could provide an important stimulus for science-based Global Public Goods.

So far, so good. But there was a significant intersection with another outcome of the 2000 meeting: the approval of a recommendation to implement testing of a regional approach to research planning.[48] This idea drew considerable interest at the regional level and GPGs were defined somewhat ambiguously as being "global, regional, or *subregional* in focus…" In the discussions in 2001, there was significant support for the Global dimension (especially in the case of genebanks), but some donors and other groups wanted the Regional dimension raised in importance. And a few preferred that the term Global be dropped (in some more extreme cases for a almost totally Regional approach). Bottom-up participatory planning was also emphasized by some, although its role at the global level is

[47] Their analysis led to the observation that "…a substitution of current R&D funding from public to private would increase productivity in the short term (0-10 years), but would tend to reduce the rate of progress in the longer term (beyond 15 years)."

[48] TAC perceived the relative role of the regional programs as follows: "In addition to regional perspectives, the CGIAR is pursuing objectives at the global level, which are not simply the aggregation of regional research needs." "Thus "…within a region, the CGIAR will be pursuing objectives that are partly, and potentially largely, coincidental with national and regional objectives, but also partly distinct" (de Janvry and Kassam, 2001).

somewhat obscure for science-based technologies where the broader and longer-term social benefits are likely to be undervalued by participants in the process.[49] The final summary of the meeting referred only to the implementation of Challenge Programs. *Sic transit gloria mundi?*[50]

Perhaps not. A Science Council is being established with a charge to think even more broadly than the CGIAR system. The interim Science Council (iSC) established criteria for judging proposals: one was "strongly international public-goods oriented". And the first three proposals recommended by the iSC - biofortified crops, genetic diversity, and water and food - are global in nature.[51] Each proposal provides for a wide range of partners, many of whom would be involved through a competitive grants program.

There is, however, a substantial question concerning funding. The initial three proposals carry a substantial initial price tag, totaling about $35.5 million per year at a minimum. An initial criterion for the program was "prospects/potential for attracting new funding", but this situation is, with one striking exception, rather nebulous at present.[52] To get the Challenge Programs started and provide continuing support, the World Bank at one point indicated that it planed to shift one third of its unrestricted funding into CP projects. Some other donors may follow suit, but to an unknown degree. To the extent that this occurs, there will be an opportunity cost in terms of existing center core activities - yet another example of the perils of trying to obtain and maintain long-term institutional support for research-based GPGs.

VII. Concluding Remarks

An important and increasing proportion of the most important problems of humanity are multi-regional or global in nature and require a substantial involvement by the public sector. The need for such activities will, if anything, increase in the future. In this setting, as Stiglitz (1999) has commented: "The concept of global public goods is a powerful one. It helps us think through the special responsibilities of the international community." It

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[49] See: Pingali, Rozelle, and Gerpacio (April 2001); and Merrill (1962). Producers are, naturally, more likely to favor research that provides producers surplus than consumers surplus (see de Gorter and Zilberman, 1990, and Roseboom, 2002b). More philosophical questions concerning representation in decision-making in "Well-Ordered Science" are discussed by Kitcher (2001).

[50] This is not to diminish the importance of more purely regional public goods, but simply transforming the already limited global or multi-regional CGIAR activities into regional programs would carry a very high opportunity cost. The regional public goods issue is more complex than it might seem (see: Cook and Sachs, 1999; Ferroni, 2001; and Stalgren, 2000).

[51] At a meeting on September 24, 2002, the Executive Committee of the CGIAR decided to recommended the first and third projects to the Annual General Meeting of the CGIAR in late October, but felt that the second, genetic diversity, needed some further refinements.

[52] The Dutch government has announced a grant of 25 million Euros (abount $25 million) to the water and food challenge program over a five year period. Other donors may be in a better position to take action once the projects are formally approved by the CGIAR.

may also facilitate communication and interaction between a fairly diverse array of groups and programs and with a wider lay audience.

In retrospect, it is curious that all of this has taken so long to unfold. As Sachs said in his speech to the CGIAR in October 2000: "…international public goods are not just a nice thing that we need to add on. They are the fundamental thing that's been missing from our template for the past 30 years" (Sachs, 2000b). And as Summers told the United Nations Economic and Social Council in July 2000: "…global public goods need to have a much more prominent place on our development agenda than they have had to date." He went to remark that: "We've had enough success with the Consultative Group on International Agricultural Research; the success in spurring the green revolution...to show that global public goods can be provided and can make a difference."

Thus the concept of global scientific public goods as pioneered by the CGIAR would seem to be coming of age and the group should be riding high. Moreover, the general climate for foreign assistance, as demonstrated at the Monterrey conference on development aid in March 2002 appears to be improving. But it remains to be seen how much of a net increase in aid funding might be forthcoming and the degree to which it will be allocated to global and regional public goods research. And even if the latter happens, the CGIAR will face increasing competition for such funding, some longer-term constraints faced by three of its major donors, and continuation of the recent shift toward restricted funding.[53]

The donors who provide most of the CGIAR funding are principally general development organizations. Research and science for development may hold a tenuous position in the face of other more immediate pressures or constraints.[54] Moreover, these organizations are primarily oriented to bilateral programs. Kremer (2002) has observed that "the country-based nature of much development assistance leads to an under-emphasis on global public goods, in particular research and development (R&D) on the health and agricultural problems of developing countries." Kanbur (2001) has gone on to suggest that "…the new realities mean that the aid system will have to (i) allocate a greater share of aid resources to cross-border externalities and international public goods…(iii) skew resources more in favor of sectoral agencies in sectors with major international public goods." And in terms of an issue that has recently come to the fore – the association of

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[53] The overall funding problems are, ironically, particularly troublesome for the two co-sponsors who have recently been particularly active in highlighting the importance of public goods. UNDP reduced CGIAR funding from an average level of $7.6 million over the 1982-96 period, to $4.5 million in 1997, to $0.5 million in 2000 (CGIAR, annual). There is also a possibility of a contraction of World Bank funding in the future because of the many other pressures on its limited grant funding (which comes from earned income). The Bank contribution is particularly important because of its unrestricted nature. The unrestricted funding situation also worsened in 2002 due to a decline in foreign aid by Japan which fell particularly heavily on the CGIAR (non-treaty multilateral contributions which lack a relatively strong domestic constituency are especially vulnerable in times of budget shortfalls).

[54] I reviewed (anonymously) the early experiences of the U.S. government in international agricultural research in detail in National Academy of Sciences (1977). More recent observations are found in Dalrymple (2000).

aid with good policy on the part of the recipient - Burnside and Dollar (2001) found no significant association at the country level but did note that aid that is managed multilaterally "…is allocated in favor of good policy." Others, concerned with the prospect that increased funding of multilateral programs might "come at the expense of [traditional] development assistance flows, particularly those directed to the poorest developing countries", have proposed that global public goods - because they might benefit donors as well - be placed into a separate accounting category and represent additional financing. (World Bank, 2001; Kaul and Le Goulven, 2001)[55]

Beyond a larger seat at the traditional donor table, which may not be easily obtained, the CGIAR and potentially similar research programs such as the proposed Global Health Research Fund (WHO, 2001) also need increasing support from more general sources of public scientific funding. These sources exist at the national level in many countries – such as the National Science Foundation or the National Institutes of Health in the United States – but are not strongly internationally oriented.[56] However, even these programs do not provide institutional support, but are directed to competitive grants. Some further international mechanism may be needed for the funding of applied science. Skolnikoff noted in 1971 that there had been proposals for an international science foundation and that "Such a foundation may be the only way to get adequate research and development on subjects determined by international needs…That argument would be particularly relevant to less developed countries." There is an International Foundation for Science, headquartered in Stockholm, but it has rather limited resources and is oriented to relatively small grants to developing country scientists.[57] Much more is needed.

In these respects, then, the CGIAR and possibly kindred institutional efforts share the classic under-funding problem faced by any public good activity – but it is magnified by their international nature and by their focus on research. While they have the capacity to make important contributions to the poorer members of society in developing nations, they will be constrained by the level and conditions of public funding. Their Global Public Goods nature is at once their major strength and their major weakness. Maintaining and encouraging such institutions and activities is indeed a global challenge. Much depends on how well this challenge is met.

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[55] The more important question, which seems to be neglected in this view, is which approach – or blend of approaches - will produce the highest absolute impact in the developing country or developing countries more generally.

[56] International center scientists may participate in grant proposals submitted by U.S. groups and institutions to, say, the National Science Foundation, but there are few such examples. One basic problem is that CGIAR centers are applied research organizations, whereas grants are usually for more advanced research. This orientation, however, would be broadened by a section of an authorization bill for a plant biotechnology program, to be administered by the Foundation, passed by the U.S. House of Representatives (HR2051) on May 14, 2002. The bill has a clear global dimension and provides for the establishment of partnerships between U.S. and developing country research organizations.

[57] Further information on this organization may be obtained from its web page: [www.ifs.se/.].

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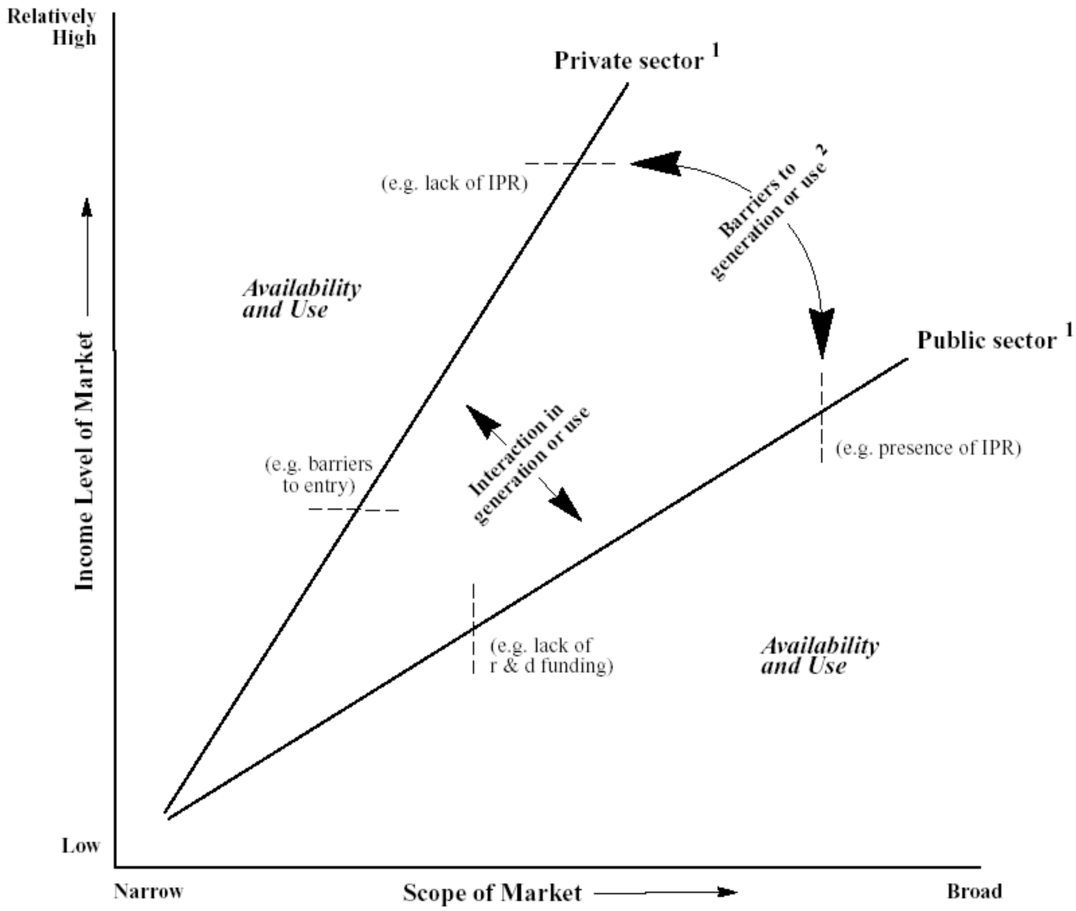
Annex

Conceptual Relationship of Factors Influencing Availability and Use of Research-Based Public and Private Sector Goods



Key: IPR = intellectual property rights

Notes:

1 The sector lines displayed show only one of many possible configurations. In this perhaps extreme case, clear market segmentation is presumed, with (1) the *private* sector providing more elite goods (probably incorporating IPR) for wealthier commercial farmers, and (2) the *public* sector providing more ordinary goods which are less profitable for the private sector and which reach more broadly across the market. In other cases, the sector lines might be curved, closer together, congruent, overlapping, or fuzzy. Certain private sector firms could, for instance, be more like the public sector and vice versa, at least for a portion of their activities. The area between the public and private sector lines might be viewed as the portion of the potential market not adopting the research-based good.

2 The limitations, more generally, could take a variety of forms such as political, legal, biological, or environmental. Public resistance to products perceived to be the product of genetic engineering has been an increasingly important barrier. The positioning of the barrier may vary by sector and for individual components. Some may be common to both sectors.