Agricultural R&D in the Developing World

Agricultural R&D in the Developing World: Too Little, Too Late?

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Dedicated to Derek Edward Tribe, 1926–2003,
who, as the first executive director of Australia's Crawford Fund,
believed passionately in and worked tirelessly for
the support of international agricultural research.

We still have not developed a set of successful public programs for investing in agricultural research and technology in poor countries . . . the investment in general is woefully inadequate both in the manner in which it is being accomplished and in the amounts spent for this purpose.

—Theodore W. Schultz, What ails world agriculture? *Bulletin of the Atomic Scientists,* January 1968. Reprinted in V. W. Ruttan, A. D. Waldo, and J. P. Houck, *Agricultural policy in an affluent society.* New York: W. W. Norton and Company, 1969, pp. 299–300.

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Foreword

This book was conceived as a companion to the 1999 volume *Paying for Agricultural Productivity,* published by Johns Hopkins University Press in conjunction with IFPRI. That volume dealt with investments, institutions, and policy processes regarding agricultural R&D in developed countries. This book addresses the same set of issues for the developing countries, and the relationship of those countries to the richer parts of the world where the preponderance of agricultural innovation still takes place. It also reviews developments within the Consultative Group on International Agricultural Research (CGIAR), along with the changing roles of international research generally, in light of the substantial shifts in science funding and policy (as well as in the science itself) that are taking place throughout the world.

The book combines new evidence with economic theory and an economic way of thinking about science policy—highlighting the developing-country aspects—as well as a set of in-depth, comparative country studies. These country studies take us well beyond generalities, providing insights into the important changes taking place within these countries and others they represent. The countries covered include the largest developing countries—China and India—as well as a range of richer and poorer, and more- and less-developed countries, representing most parts of the globe.

The evidence and ideas presented in the book are disquieting. Over the past several decades, at least, spillovers of agricultural technology from rich countries to poor countries demonstrably increased productivity and food security for many parts of the developing world. As the authors document, however, recent developments in both the developed and developing worlds mean that poor countries may no longer be able to depend as they have in the past on spillovers of new agricultural technologies and knowledge from richer countries, especially advances related to enhanced productivity of staple foods.

As a consequence of these changes, simply maintaining their current agricultural R&D policies may leave many developing countries as agricultural technology orphans in the decades ahead. Developing countries may have to become more self-reliant and perhaps more dependent on one another for the collective benefits of agricultural R&D and technology. Some of the more advanced developing countries like South Korea, Brazil, China, and India seem to be gaining ground, with productive and self-sustaining local research sectors taking hold. However, other parts of the developing world, as illustrated in this book by reviews of agricultural R&D in Zambia, Bangladesh, and Indonesia, are merely regaining lost ground or slipping further behind. Aside from a handful of larger countries, many developing countries, especially in Africa, are facing serious funding and institutional constraints that inhibit the effectiveness of local R&D. Together, these factors may lead to serious food deficits.

The information assembled here and the lessons learned in this volume argue for refocusing attention on agricultural R&D as an instrument for long-run economic development to help avert a continuation of the chronic hunger and malnutrition that afflict all too many people around the world. These lessons will pay off if they help revitalize multinational engagement and investment in the global public benefits of international agricultural research.

Joachim von Braun
Director General, IFPRI

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The editors acknowledge with gratitude the outstanding assistance of Mary Jane Banks, Sue Pohlod, Louise Letnes, and the staff in the Communications Division at IFPRI who helped turn our chapter files into a coherent book manuscript. We also received extensive and excellent comments from Stanley Wood and two anonymous reviewers, and helpful guidance from IFPRI's Publication Review Committee. Finally, we owe a big debt of gratitude to the authors of the country chapters, who worked willingly with us through multiple rounds of revisions.

Chapter 1

Introduction and Overview

Julian M. Alston, Philip G. Pardey, and Roley R. Piggott

In the early 21st century, the science of agriculture has started to shift gears, just as it did 100 years ago. At the beginning of the 20th century, Charles Darwin's theory of evolution, the pure-line theory of Wilhelm Johannsen, and the rediscovery of Gregor Mendel's laws of heredity contributed to the rise of plant breeding, while Louis Pasteur's germ theory of disease and the development of vaccines opened up lines of research in the veterinary sciences. The next epoch in agricultural technology will also have fundamental biological science at its foundation. Today, scientists armed with new molecular biologies involving genomics, proteomics, recombinant DNA, and supporting informatics technologies are delving deeper into the genetics of life, with potentially profound and pervasive implications for agriculture worldwide.

The context in which that science will take place has evolved and shifted as well. The public purpose in agricultural R&D is less focused and more closely scrutinized than it was a century ago; the general public seems less trusting of some areas of science, and perhaps of some scientists (National Science Board 2002); and marked changes are taking place in the intellectual property regimes relating to the genetic resources used in agriculture and the technologies used to transform them (Boettiger et al. 2004; Pardey, Koo, and Nottenburg 2004). Complacency has crept in too. Some question the need for continued public funding at recent levels, suggesting that the world's food problems are being solved or constrained by things other than R&D, or that the private sector will do the job (see Runge et al. 2003). Others see a scientific apartheid taking shape, with large parts of the developing world being left behind or denied the prospects science has to offer for growth, development, and prosperity (Serageldin 2001).

The world's agricultural economy was transformed remarkably during the 20th century. The agricultural productivity growth that fueled this change was generated primarily by agricultural R&D financed and conducted by a small group of rich countries—especially the United States, but also Japan, Germany, and France. In an increasingly interdependent world, both rich and poor countries have depended on agricultural research conducted in the private and public laboratories of these few countries, even if they have not contributed to financing the activity.

But now the rich-country research agendas are shifting. In particular, they are no longer as interested in simple productivity enhancement. Dietary patterns and other priorities change as incomes increase. Food-security concerns are still pervasive among poor people, predominantly in poor countries. In rich countries we see a declining emphasis on enhancing the production of staple foods and an increasing emphasis on enhancing certain attributes of food (such as growing demand for processed and so-called functional foods) and on food production systems (such as organic farming, humane livestock production systems, localized food sources, and "fair trade" coffee). In addition to growing differences between rich and poor countries in consumer demand for innovation, research agendas may diverge because of differences in producer and processor demands. Farmers in rich countries are demanding high-technology inputs that often are not as relevant for subsistence agriculture (such as precision farming technology or other capital-intensive methods). As well as differences in value-adding processes to serve consumer demands, differences in farm production technologies are emerging to serve the evolving agribusiness demands for farm products with specific attributes for particular food, feed, energy, medical, or industrial applications.

As rich-country research responds to these changing patterns of demand, the emphasis of the science is shifting in ways that could undermine the international spillovers that contributed significant past gains in food production throughout poorer countries. These spillovers are not generally well understood, and their importance is underappreciated (Alston 2002).

Other aspects of agricultural science policy, and the context in which research is done, are changing as well. In particular, the rise of modern biotechnology and enhanced intellectual property rights (IPR) regimes mean that technologies that were once freely accessible will be less accessible in the future. Moreover, the new technologies may not be as portable as in the past. Biotech companies, which are mostly located in the rich countries—particularly in the United States—emphasize technologies that are applicable at home. These and other factors limit incentives for companies to develop technologies for less-developed countries (Bradford et al. 2004). Hence some fear that less-developed countries will become technological orphans, abandoned by their former private- and public-sector benefactors in rich countries (see, for example, Pinstrup-Andersen and Cohen 2001).

In *Paying for Agricultural Productivity,* Alston, Pardey, and Smith (1999) documented the changing institutions and investments in agricultural R&D in a selection of rich countries.[1] In many countries, toward the end of the 20th century public and private roles shifted, and support for public agricultural research slowed, especially for near-market, applied, productivity-enhancing research. Slower-growing, stagnant, or shrinking public agricultural research funds are increasingly being diverted toward environmental objectives, food quality and safety, and so on. Who, then, will do the research required to generate sustenance for a growing world population when—at least for another century—virtually all population growth will occur in the poorer parts of the world?

The purpose of this volume is to document the changing institutions and investments in agricultural R&D in less-developed countries, in part to form a companion volume to *Paying for Agricultural Productivity* by providing a more complete global picture of the issues. A more important purpose is to take stock of what is happening in less-developed countries. This task is especially compelling if, as seems likely, these countries will have to become more self-reliant in developing crucial new agricultural technologies.

In Chapter 2 we set the scene for the chapters that follow. We introduce some economic principles for government intervention in agricultural research, along with detailed data on the evolving patterns of agricultural research spending around the world. Chapters 3 through 11 cover nine countries, including the most important among the less-developed countries, in terms of total investment in agricultural R&D.[2] The case-study countries include a reasonable representation of countries from Asia, Latin America, and Africa. Some basic features of the economies of these countries (plus the United States for comparison), are summarized in Table 1.1, including measures of their overall size, structure, economic policies and performance, and institutional infrastructure; and measures of the key features of their agricultural sectors, such as primary products, agriculture's share of GDP and the workforce, and agroecological attributes.

The chapters document the history and current status of the national agricultural research systems (NARSs) in terms of policies, institutions, investments, and achievements. The case studies cover a geographically dispersed area (South Africa and China, for example) and diverse farming systems (such as Brazil vs. Korea), yet some common themes emerge.

In addition to these country-specific chapters, Chapter 12 addresses the collective multinational effort to provide agricultural R&D through international

Table 1.1 Profiles of case-study countries

Indicator	Bangladesh	Brazil	China	Colombia
Economy-wide indicators				
Population (2003, millions)	138.1	176.6	1,288.4	44.6
Urbanized (2003, percent of total population)	27	83	39	76
GDP (2003, billions)				
Current international dollars	244.4	1,375.8	6,446.0	298.8
Current U.S. dollars	51.9	492.3	1,417.0	78.7
GDP per capita (2003)				
Current international dollars	1,770	7,790	5,003	6,700
Current U.S. dollars	376	2,788	1,100	1,765
Growth in GDP per capita (1993–2003, percent per annum)	3.1	1.1	7.7	0.4
Trade shares, 2002				
Value of exports in GDP (percent)	14	15	29	20
Value of imports in GDP (percent)	19	13	26	21
Communications (per 1,000 people)				
Telephone mainlines, 2002	5	223	167	179
Mobile phones, 2003	10	264	215	141
Internet users, 2003	2	82	63	54
Road density, 1999 (km per km^2)	1.59	0.20	0.14	0.11
Percentage of roads paved, 1999	10	6	22	14
Economic freedom index, 2005	3.95	3.25	3.46	3.21
Ranking (out of 161)	141	90	112	88
Trade policy	5	4	4	4
Property rights	4	3	4	4
Corruption perceptions index, 2004	1.5	3.9	3.4	3.8
Corruption perceptions (ranking out of 145)	145	59	71	60
Agricultural indicators				
Agricultural value-added, 2001				
Current international dollars (bilions)	52.6	78.6	852.0	37.7
Percent of GDP	24	6	16	14
Population actively engaged in agriculture, 2004 (percent of total)	52	15	64	18
Top five agricultural products by value (average 2001–03, percent of total)	Rice 64 Beef and veal 4 Goat milk 3 Potatoes 3 Pimento 3	Beef and veal 22 Soybeans 13 Chicken meat 11 Sugarcane 8 Cow milk 8	Pig meat 17 Rice 10 Hen eggs 6 Maize 4 Wheat 4	Beef and veal 19 Cow milk 18 Chicken meat 9 Coffee 8 Sugarcane 7

India	Indonesia	South Africa	South Korea	Zambia	United States
1,064.4	214.7	45.8	47.9	10.4	290.8
28	44	59	84	40	78
3,078.0	721.5	474.1	861.0	9.1	10,923.4
600.6	208.3	159.9	605.3	4.3	10,948.6
2,892	3,361	10,352	17,975	875	37,563
564	970	3,491	12,637	413	37,650
4.3	1.6	0.7	4.4	–0.6	2.1
15	36	34	35	24	10
16	29	30	34	29	14
40	37	107	489	8	646
25	87	364	701	22	543
17	38	58	610	6	551
0.85	0.20	0.30	0.88	0.90	0.69
57	57	20	75	22	59
3.53	3.54	2.78	2.64	3.40	1.85
118	121	56	45	106	12
5	2	2	3	3	2
3	4	3	2	3	1
2.8	2.0	4.6	4.5	2.6	7.5
90	133	44	47	102	17
658.5	109.6	13.2	30.3	1.8	198.6
25	17	3	4	22	2
58	46	8	8	67	2
Rice 18	Rice 37	Beef and veal 16	Pig meat 17	Maize 15	Maize 17
Buffalo milk 11	Coconuts 6	Maize 14	Rice 15	Beef and veal 16	Beef and veal 16
Wheat 8	Palm oil 6	Chicken meat 12	Cow milk 7	Cassava 10	Cow milk 11
Cow milk 7	Maize 5	Cow milk 8	Hen eggs 6	Hen eggs 7	Chicken meat 10
Sugarcane 4	Cassava 4	Grapes 5	Beef and veal 6	Chicken meat 7	Soybeans 10

(*continued*)

Table 1.1 (continued)

Indicator	Bangladesh	Brazil	China	Colombia
Area of agricultural land (avg 1999–2001, thousand km^2)	91	2,619	5,496	457
Percentage of total land area	70	31	59	44
Percentage of agricultural land irrigated	46.2	1.1	9.9	2
Percentage of agricultural land arable and permanently cropped	93.4	25	27.2	.6
Percentage of agricultural land permanently pastured	6.6	75	72.8	90.4
Agroecological attributes (percent of ag)				
Temperate				
Irrigated and mixed irrigated	0	0	18.8	0
Rainfed	0	0	35.3	0
Moderate cool tropics	0	15.0	38.7	30.9
Warm tropics and subtropics				
Irrigated and mixed irrigated	56.6	1.1	1.0	10.9
Sloped rainfed	2.0	18.0	1.7	22.0
Flat rainfed	41.4	65.9	4.5	36.1

Sources: Data for population (total and urbanized), GDP, GDP per capita, growth in GDP per capita, trade shares, telephone mainlines, mobile phones, Internet usage, road density, proportion of roads paved (except for China), and agricultural value-added are from World Bank 2005. Data for China's proportion of roads paved are from CIA 2005. Data for the economic freedom index are from Miles et al. 2005. Data for the corruption perception index are from Transparency International 2005. Data for population actively engaged in agriculture are from Table A.3 in FAO 2005a. Data for quantity of agricultural production by value are from FAO 2005b, weighted by commodity-specific international prices averaged over the 1989–91 period from unpublished FAO data files. Shares of agricultural area in total and in a given agroecology are calculated from data and digitized maps underlying Wood et al. 2000.

Notes: GDP per capita in current U.S. dollar units was calculated from respective GDP and population data in World Bank 2005. The growth in GDP per capita was calculated by taking the average of the difference in natural logs for GDP per capita (in constant

agricultural research centers, emphasizing the Consultative Group on International Agricultural Research (CGIAR) system. Chapter 13 presents a synthesis of the main themes and issues from the case studies, and directions for policy change to address these issues.

The Audience

This book has been written primarily for those who make policy and allocate resources for agricultural research and extension, and the policy analysts and development specialists who advise them: specifically, strategic decision makers and their advisers in international agencies, national governments, and public or private agricultural research and extension organizations. These decision makers must gauge

India	Indonesia	South Africa	South Korea	Zambia	United States
1,807	445	996	20	353	4,122
61	25	82	20	47	45
30.3	10.8	1.5	60	0	5.4
94	74.8	15.8	95	15	43.2
6	25.2	84.2	5	85	56.8
0	0	0	43.4	0	5.6
0	0	0	56.4	0	66.7
5.2	0.5	77.4	0.2	5.1	22.5
47.9	27.7	2.2	0	0	0.7
8.7	32.2	3.3	0	18.6	1.6
38.3	39.5	17.1	0	76.2	2.9

local currency units) over the years 1993 to 2003. The proportion of paved roads for China was calculated from respective data within CIA 2005. Internet usage figures for Brazil, South Africa, and the United States are 2002 (not 2003) data. The economic-freedom index ranges from 1 (most free) to 5 (most economically repressed); the general index is constructed from subratings based on trade policy, fiscal burden of government, government intervention in the economy, monetary policy, capital flows and foreign investment, banking system and finance, wages and prices, property rights, regulation, and informal market; the highest-ranking country is Hong Kong, with an index of 1.35. The corruption perceptions index ranges from 0 (highly corrupt) to 10 (highly clean); the highest-ranking country is Finland, with an index of 9.7. Agricultural land includes arable, permanently cropped, and permanently pastured land. International dollars are obtained by currency conversion using purchasing power parity (PPP) indexes, which compare prices across a broader range of goods and services than conventional exchange rates.

the adequacy and appropriateness of research activities for which they are responsible and build the new institutions for R&D that will facilitate sustained growth and development in the decades ahead. The information should also be of interest to students and scholars who seek to know what has happened in agricultural R&D and why, and to understand the consequences in ways that may lead to better-informed policy choices. Understanding the histories of public agricultural research institutions and the forces of change that confront each system, and learning from the changes made to address these external forces, will provide a basis for formulating public agricultural R&D policies that are both politically feasible and economically worthwhile. Beyond these primary audiences, the material in this book should also be accessible and of interest to farmers, food processors, wholesalers, retailers, environmentalists, scientists, and all who have a direct stake in, or are affected by, the agricultural research system, as well as those generally interested in development and development economics.

Notes

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1. See also Alston, Pardey, and Taylor (2001) and Pardey and Beintema (2001).

2. The most significant deficiency in country coverage is that we do not include any of the countries of the former Soviet Union.

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Chapter 2

Developing-Country Perspectives on Agricultural R&D: New Pressures for Self-Reliance?

Julian M. Alston and Philip G. Pardey

This chapter provides a conceptual and empirical context for the case studies in Chapters 3 through 12. First, we briefly discuss the nature of market failures in agricultural research—both among firms within a country, and among nations—and the roles for government intervention in general. Next, we consider the distinguishing features of less-developed countries and what they might imply for R&D policy. We also discuss the important role of agricultural R&D and technology spillovers among nations, and the past dependence of the world's poorest countries on their richer neighbors. Next, we document the longer-term global story of institutions and investments in agricultural R&D, emphasizing the great importance of past achievements in agriculture and recent changes that leave grounds for concern about the prospects for the next 20 years and beyond. In the light of these facts, we contemplate the prospects for the future and the implied need to reinvent international collective action in agricultural R&D and reinvest in the associated global public goods institutions.

The presentation of facts and ideas here is brief, in recognition of both space limitations and the availability of the more complete treatments upon which much of this discussion draws. The in-principle arguments about the economics of agricultural R&D policy are based on Chapter 2 in *Paying for Agricultural Productivity,* by Alston and Pardey (1999); our discussion of trends in research funding borrows heavily from Pardey et al. (2006) and Chapter 3 in *Paying for Agricultural Produc-*

tivity, by Pardey, Roseboom, and Craig (1999). We refer readers interested in a more complete treatment to these source documents; however, our contribution involves more than simply taking that material and summarizing it. In considering the specific perspective of less-developed countries, we reinterpret and tailor the ideas and arguments, and bring to bear different facts.

Policy Principles

Alston and Pardey (1999) laid out the case for government intervention in agricultural R&D and relevant principles for the determination of the appropriate form and extent of intervention. These arguments are useful for contemplating past and prospective policy changes. The key idea is that incomplete or ineffective property rights over inventions can lead to market failure in agricultural R&D, which means that inventors are unable to fully appropriate the returns to their research investments. Market failures in research can happen at the level of firms within a state or country, states within a country, or among countries—in any context where the distribution of benefits from adopting the results does not closely match the distribution of the costs incurred in doing the research.

Market failure leads to private-sector underinvestment in agricultural R&D, a phenomenon that can account for the consensus in the empirical literature dealing with different commodities and different countries, that agricultural R&D has been, on average, a highly profitable investment from society's point of view (Alston et al. 2000). In turn, this outcome suggests that research may have been underfunded, and that current government intervention may be inadequate.[1]

This is not to say that the amount of government spending necessarily should increase. Changes in government intervention can take many forms. Some commentators propose increasing R&D funding from general government revenues, but this is only one possible alternative. Governments can also change the incentives for others to increase their investments in private or public R&D (as well as influence what research is done, by whom, and how effectively). A premise that government intervention is inadequate implies simply that the nature of the intervention ought to change so as to stimulate either more private investment or more public investment. Policy options available to the government for stimulating private funding or performance of agricultural R&D include

- improving intellectual property protection;
- changing institutional arrangements to facilitate collective action by producers, for instance, by establishing levy arrangements; and

- encouraging individual or collective action through the provision of subsidies (or tax concessions) or grants in conjunction with levies.

Intellectual property rights are applicable or enforceable only for certain types of inventions, and they have the disadvantage that privately optimal prices may exceed socially optimal prices.[2] Commodity-specific levy arrangements are most applicable for commodity-specific R&D of a relatively applied nature (as implemented in Australia, Colombia, and Uruguay, for instance), although more general agricultural R&D could be funded by a more general agricultural levy (as in the Netherlands). In cases where the fruits of invention can be only partially appropriated, a case can be made for partial support from general government revenues through subsidies or matching grants in conjunction with commodity levies, as used in the Australian R&D corporations (see, for example, Alston, Freebairn, and James 2004). To some extent, questions about how to finance agricultural R&D can be separated from who conducts the research, what research is undertaken, and how the R&D process is managed. It is useful to consider these elements as separate issues, but inevitably they become intertwined.

In addition to efficiency gains from increasing the total R&D investment, the government can also intervene with a view to improving the efficiency with which resources are used within the R&D system. Changes over time in economic circumstances imply changes in R&D institutions. Some research activities that were once clearly perceived as the province of the government have become part of the private domain. Examples include much applied work into the development and evaluation of new agricultural chemicals and new plant varieties.

Both in one country over time, and among different countries at the same time, circumstances differ in ways that call for different policies and institutional arrangements. Policies must be suited to the setting. Some restructuring or consolidation of agricultural R&D institutions, in some instances on a geographic basis, is warranted by the changing nature of the research being undertaken; its focus relative to agriculture, agribusiness, and the environment; and the spatial and economic applicability of the results, as well as the changing nature of economies of size, scale, and scope in research. In addition to changes in the organization of research institutions, there is also scope for more economic rationalism in the processes for managing research and allocating research resources and in the structure of incentives for scientists.

Distinctive Features of Less-Developed Countries

These general notions about market failure and options for government action apply generally, but with different specific implications as cases change. Less-developed countries tend to differ from more-developed countries in some systematic ways. In particular, for a number of reasons, the phenomenon of private-sector neglect and national underinvestment in agricultural R&D is likely to be more pronounced in less-developed countries than in developed ones. Why is this so, and what does it imply?

First, less-developed countries are commonly characterized as having a comparatively high incidence of incomplete markets, resulting from high transaction costs and inadequate property rights, which in turn may be attributable to inadequate infrastructure and defective institutions, among other things. To the extent that they exist, information problems, high transport and communications costs, poorly functioning credit markets, and the like, combined with the limited education of some farmers, are likely to make it harder to capitalize on new inventions. In rich countries, we might discount the issues of risk and capital costs as disincentives to investment in invention, but in less-developed countries these factors might take on a greater importance, especially if capital markets do not function well—for whatever reason.

Second, the types of technology often suited to less-developed country agriculture have hitherto been of the sort for which appropriability problems are more pronounced—types that have been comparatively neglected by the private sector even in the richest countries. In particular, until recently, private research has tended to emphasize mechanical and chemical technologies, which are comparatively well protected by patents, trade secrecy, and other intellectual property rights; and the private sector has generally neglected varietal technologies except where the returns are appropriable, as for hybrid seed (see Olmstead and Rhode 2002). In less-developed countries, the emphasis in innovation has often been on self-pollinating crop varieties and disembodied farm management practices, which are the least appropriable of all. The recent innovations in rich-country institutions mean that private firms are now finding it more profitable to invest in plant varieties; the same may be true in some less-developed countries, but not all countries have made comparable institutional changes.[3]

Third, in many less-developed countries, prices have been distorted by policies in ways that diminish incentives and opportunities for farmers to adopt new technologies (see Schultz 1978; Alston and Pardey 1993; and Sunding and Zilberman 2001).[4] Only when we achieve a reasonable rate of inventor appropriability of the returns to the technologies that are applicable in less-developed countries, combined with an economic infrastructure that facilitates adoption of those technologies, can we expect a significant private-sector role to emerge.

Accepting that markets may fail, for whatever reason, we have to consider the possibility that governments in less-developed countries also might fail—in this case, fail to correct the underinvestment in agricultural research—for both economic and political reasons. For instance, and as a fourth factor accounting for their low rates of investment in agricultural R&D, government revenues may be comparatively expensive, or have a comparatively high opportunity cost in less-developed countries. This can be so because it is comparatively expensive to raise government revenues through general taxation measures.[5] And many less-developed countries are characterized by underinvestment in a host of other public goods, such as transportation and communications infrastructure, schools, and hospitals, as well as agricultural science (Runge et al. 2003), which might also have high social rates of return.

Fifth, there are political factors to consider. In rich countries, agriculture is a small share of the economy, and any individual citizen bears a negligible burden from financing a comparatively high rate of public investment in agricultural R&D (for instance, in the United States, the public expenditure of US$3.8 billion on agricultural R&D in 2000 amounted to less than US$14 per person per year). The factors that account for high rates of general support for agriculture in the industrialized countries can also help account for the comparatively high intensity of public agricultural research. In many less-developed countries, where agriculture represents a much greater share of the total economic activity, and where per capita incomes are much lower, a meaningful investment in public agricultural research may have a much more appreciable impact on individual citizens. This burden is felt immediately, whereas the payoff it promises may take a long time to come and will be much less perceptible when it does.

Finally, even many of the rich countries of the world have not had very substantial private or public agricultural science industries. Why should we expect the poorest countries of the world to act like the richest of the rich in this regard?[6] The lion's share of the public (as well as private) investment in agricultural science has been undertaken by a small number of countries; and these have been the countries that have also undertaken the greatest share of scientific research, more generally. Typically, these have been the large economic powerhouses, especially the United States. Differences in per capita income, the total size of the economy, and comparative advantages in science (reflecting not just wealth but also the nature of the society) may all have influenced the international distribution of the burden of agricultural R&D investments.

It might not make economic sense for small, poor, agrarian nations to spend their comparatively scarce intellectual and other capital resources in agricultural science on their own behalf in a world in which other countries can do it so much more effectively.[7] And in the past it has been an effective strategy for many nations to free-ride on the efforts of a few others in agricultural R&D. Both inadvertent technology spillovers and international initiatives such as the CGIAR and bilateral agricultural R&D development aid might have crowded out some national investments in agricultural R&D in less-developed countries.[8]

An important consideration is economies of size, scale, and scope in research, which influence the optimal size and portfolio of a given research institution. In some cases the "optimal" institution may efficiently provide research for a state or region within a nation, but for some kinds of research the efficient scale of institutions may be too great for an individual nation (see, for example, Byerlee and Traxler 2001). Many nations may be too small to achieve an efficient scale in any of the relevant elements of their agricultural R&D interests, except perhaps in certain types of adaptive research. A particular problem for efficiency in agricultural science, especially for many smaller countries, is that there are few effective institutions for financing and organizing research on a multinational basis when the research is applicable across multiple countries, and individual countries are too small to achieve efficient scale (see Chapter 12 in this volume).

Technology Spillovers: Past, Present, and Future

The history of agricultural development shows that agricultural technology need not be home-grown; over the years it has been bought, borrowed, and stolen. For instance, in the late 18th century, Thomas Jefferson, risking the death penalty, smuggled rice seeds out of Italy in the lining of his coat to encourage cultivation of the crop in South Carolina. Agricultural innovations move across borders, both by design and by accident. These technology spillovers imply both international market failures and a case for multinational government action to correct them, paralleling the intranational arguments presented above.

R&D spillovers among geopolitical entities arise when research conducted by one state (or nation) confers benefits on other states (or nations) that are able to adopt the results. Such spillovers have two kinds of implications for research policy. First, they add complications to already awkward policy questions that arise when research is being conducted and funded by state and national governments—such as how much and what mix of research should be undertaken, who should pay for it, who should do it, and what institutional arrangements should be put in place. Second, and perhaps more important, they introduce an additional dimension to incentive problems. The fundamental economic basis for the government support of agricultural research is incomplete appropriability of research benefits by inventors. Research and technology spillovers among research providers within a state can be addressed (at least in principle) by state-government policy, but state-government policy cannot effectively address spillovers across state boundaries.

Similarly, federal-government policy might address spillovers among research providers in different states within a nation, but national-government policy cannot effectively address spillovers among nations.

Alston (2002) reviewed the evidence of agricultural R&D spillovers, with emphasis on the international dimension. The main findings can be stated simply. First, intranational and international spillovers of public agricultural R&D results are very important. In the small proportion of studies that have taken them into account, spillovers were responsible for a sizable share—in many cases, more than half—of total measured agricultural productivity growth and the corresponding research benefits. Second, spillovers can have profound implications for the distribution of research benefits between consumers and producers and thus among countries, depending on their trade status and capacity to adopt the technology. Third, it is not easy to measure these impacts, and the results can be sensitive to the specifics of the approach taken, but studies that ignore interstate and international spillovers are likely to obtain seriously distorted estimates of the returns to agricultural research. Finally, because spillovers are so important, research resources have been misallocated both within and among nations. In particular, international spillovers contribute to a global underinvestment in agricultural R&D that existing public policies have only partly succeeded in correcting.[9] The stakes are large because the benefits from agricultural technology spillovers are worth many times more than the investments that give rise to them.

This volume examines spillovers from a less-developed-country perspective. It is important to note the important role of spillins to the world's poorest countries of technologies from industrialized countries (especially the United States, but also the United Kingdom, France, and others), both individually and through their collective action via the CGIAR. Until recently, much of the successful innovative effort in most of the world's poorer countries applied at the very last stage of the process—selecting and adapting crop varieties and livestock breeds for local conditions using materials developed elsewhere. Only a few larger countries, such as Brazil, China, and India, were able to achieve much by themselves at the more upstream stages of the research and innovation process, even for improved crop technologies for which conventional breeding strategies are widely applied. Until recently that strategy was reasonable, given an abundant and freely accessible supply of suitable materials, at least for the main temperate-zone food crops. Changes in the emphasis of rich-country research, combined with new intellectual property rules and practices and an increased use of modern biotechnology methods, have already begun to spell a drying up of the public pool of new varieties. In addition, and as set out in detail in Chapter 12, the other main source of varietal materials—the CGIAR—has changed its emphasis and is scaling back its role in providing finished material or advanced breeding lines.[10] The reduction in spillovers from these traditional sources means that less-developed countries will have to find new ways of meeting their demands for new varieties.

Research Spending Patterns

The public and private roles in agricultural science have changed, reflecting changing economic conditions in the broader economy as well as in agriculture. Changes have also occurred in institutional arrangements, such as intellectual property rights, and in public attitudes and perceptions. Although many elements of the changes have been common to various countries, reflecting common influences at work, there have been some important divergences among countries as well—especially between the richest and the poorest countries. Pardey et al. (2006) document these changes.

General Trends

Over the last two decades of the 20th century, worldwide public investments in agricultural research increased by 51 percent in inflation-adjusted terms, from an estimated $15.2 billion (in 2000 international dollars) in 1981 to around $23 billion in 2000 (Table 2.1).[11] During the 1990s, for the first time, developing countries as a group undertook more of the world's public agricultural research than the developed countries, but with the Asian and Pacific region and China accounting for more of the developing-country total, and Sub-Saharan Africa losing market share.

What the regional totals fail to reveal is that public spending was concentrated in only a handful of countries. The United States, Japan, France, and Germany accounted for two-thirds of the $10.2 billion of public research done by rich countries in 2000, about the same as two decades before. Similarly, four of the developing countries among those included in this book—China, India, Brazil, and South Africa—spent almost 50 percent of the developing world's public agricultural research money in 2000, up from 37 percent in 1981.

Despite this pattern of strong longer-term growth in spending since the 1970s, for many parts of the world the rapid and quite pervasive growth in spending during the 1970s and early 1980s gave way to a dramatic slowdown during the 1990s. In the rich countries, public investment actually shrank by 0.58 percent annually between 1991 and 2000, compared with an increase of 2.3 percent per year during the 1980s. Spending in Africa grew by only 0.82 percent per year in the 1990s—a much slower rate than during the 1980s (1.25 percent per year). This slowing reflects a longer-run trend: rapid growth in spending in the 1960s gradu-

Table 2.1 Global public agricultural-research spending, 1981–2000

Expenditures (million 2000 international dollars)	1981	1991	2000
Developing countries	6,904	9,459	12,819
Sub-Saharan Africa	1,196	1,365	1,461
China	1,049	1,733	3,150
Asia and Pacific	3,047	4,847	7,523
Latin America and the Caribbean	1,897	2,107	2,454
Middle East and North Africa	764	1,139	1,382
Developed countries	8,293	10,534	10,191
Total	15,197	19,992	23,010
Annual growth rates (percent per year)	**1981–91**	**1991–2000**	**1981–2000**
Developing countries	3.04	2.90	3.14
Sub-Saharan Africa	1.25	0.82	0.99
China	4.76	5.04	4.86
Asia and Pacific	4.33	3.92	4.19
Latin America and the Caribbean	1.13	2.06	2.01
Middle East and North Africa	4.12	1.87	3.35
Developed countries	2.27	–0.58	1.10
Total	2.63	1.20	2.11

Source: Agricultural Science and Technology Indicators (ASTI) data underlying Pardey et al. 2006.

Note: Data are provisional estimates and exclude Eastern Europe and countries of the former Soviet Union.

ally gave way in the 1980s and beyond to debt crises, curbs on government spending, and waning donor support for agriculture in general, and agricultural R&D in particular, during the 1990s. In fact, if large countries like Nigeria and South Africa are excluded, spending for Africa overall actually declined by 2.5 percent per year during the 1990s (Beintema and Stads 2004). Spending in Asia grew by an average of 3.9 percent per year during the 1990s, compared with 4.3 percent annually during the previous decade. Growth slowed in the Middle East and North Africa as well.

China and India are exceptions. Growth in spending during the 1990s averaged 5.04 percent per year in China and 6.37 percent per year in India. Things look a little better in Latin America, too, with spending growing 2.06 percent per year from 1991 to 2000, compared with about half that rate during the previous decade. But the recovery in Latin America seems fragile and is not distributed evenly throughout the region. Public research in countries like Brazil (with public spending approaching a billion dollars a year, a considerably larger commitment than in any of the developed countries besides the United States and Japan) and Colombia did better in the early 1990s but suffered cutbacks in the later part of the decade. Many of the poorer (and smaller) countries have failed to experience any sustained growth in funding for the past several decades.