Building Science and Technology Capacity for Agriculture: Implications for Evaluating R&D

Philip G Pardey[1] and Julian M. Alston[2]

[1]Department of Applied Economics, University of Minnesota, 1994 Buford Ave, St Paul MN, 55108, USA
Email: ppardey@apec.umn.edu
[2] Department of Agricultural and Resource Economics, University of California, Davis CA 95616, USA
Email: julian@primal.ucdavis.edu

Abstract

Worldwide, agricultural R&D is undergoing a sea change. Total funding is often now growing at much slower rates than in earlier decades, the nature and sources of support for research are diversifying with the private sector doing or funding much more of the research (at least in developed countries), and there are substantial shifts in the scientific basis for much of the biological research directed toward agriculture. At the same time the institutional, regulatory and intellectual property regimes that affect agricultural R&D are themselves undergoing rapid change. Efforts to reshape pubic policies that have long-term implications for scientific and technological capacity are underway, but progress has been uneven and in many cases uninformed by evidence of the likely (economic) effects of changes in the investment and institutional realities surrounding agricultural R&D.

Media Summary

Efforts to end hunger worldwide, let alone sustain the unprecedented gains in food production over the past several decades are far from assured.. Do we have the scientific and technical capacity to successfully address these developments? Evaluating the likely effects of R&D is critical to making wise use of increasingly scare agricultural research resources.

Key words

Economic evaluations, research and development, investments, funding mechanisms

Introduction

Private ingenuity and economic activity provide the lion's share of wealth creation worldwide. But laissez-faire markets miss some socially productive opportunities. The strongest case for government intervention can be made where unfettered markets are least effective, commonly in health, education, law and order, and (especially) R&D. But the appropriate form and extent of the interventions are open questions—how much should be spent on what types of R&D, who should pay for and conduct the research, what is the right balance between doing domestic R&D and tapping technologies developed elsewhere in the world? To help address these important public policy questions, it is useful to review recent trends, the current status, and future context of agricultural R&D.

As we describe in this paper, agricultural research is in the midst of substantial but uneven change. This change involves shifts in the public and private funding and conduct of agricultural R&D, and the orientation of that research. It also encompasses substantial regulatory and institutional changes regarding the development and transfer of technologies used in food and agriculture, including changes in access to and the use of the know-how and technologies developed in other parts of the world (not least because of changing intellectual property regimes). Some of this change stems from a broad set of policy and institutional reforms that have spurred reevaluations of the proper public role in agricultural R&D and the amounts and forms of research funding. Some of the change derives from even more fundamental sectoral, macroeconomic, and trade policy reforms that directly affect food and agriculture, inducing change in the research that serves these sectors.

Despite questions being raised about the accuracy of the research evaluation evidence (not least by Alston et al. 2000), the large literature discussed in more detail below suggests that societies continue to underinvest in research. Aside from the 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.

Different economic circumstances imply different R&D institutions. Both in a country over time, and among countries at the same time, circumstances change in ways that imply different policies and institutional arrangements. Policies must be suited to the setting. 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 production and evaluation of agricultural chemicals and new plant varieties. Some restructuring or consolidation of agricultural R&D institutions, in some instances on a geographic basis, is implied 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 by 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, allocating research resources, and in the structure of incentives for scientists.

We begin with a brief review of current R&D capacities worldwide, then describe the economic and market fundamentals that will (or should) influence the evolution of these capacities into the future. Following a brief review of the agricultural research evaluation literature (in particular the economic elements of that literature) we conclude with the implications for R&D evaluations designed to inform the development of science and technological capacity.

Research and Technological Capacity

Public and private roles in agricultural science have changed, and while many elements of the changes have been common among countries, reflecting common influences at work, there have been some important divergences among countries as well— especially comparing the richest and the poorest countries.

Investment trends

General developments. Over the past three decades, worldwide, public investments in agricultural research nearly doubled in inflation-adjusted terms, from an estimated $11.8 billion (1993 international dollars) in 1976 to nearly $21.7 billion in 1995 (Table 1) (Pardey and Beintema 2001). These data reveal a historical first: during the 1990s, 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 as well as 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 the public spending was concentrated in only a handful of countries. Just four 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 1995, about the same as two decades before. Similarly, three of the developing countries—China, India, and Brazil—spent 44 percent of the developing world’s public agricultural research money in 1995, up from 35 percent in the mid-1970s.

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 in the first half of the 1990s. In the rich countries, public investment grew just 0.2 percent annually between 1991 and 1996, compared with 2.2 percent per year during the 1980s. In Africa, there was no growth at all—the continuation of a longer-run trend, with rapid growth in spending in the 1960s, gradually giving way to debt crises in the 1980s and curbs on government spending and waning donor support in the 1990s. Preliminary results from new surveys of African countries suggest no substantial recovery in the latter part of the 1990s, with spending totals possibly shrinking for the region if large countries like Nigeria and South Africa are excluded (Beintema 2004). Spending in Asia grew by an average of 4.4 percent per year during 1991–96, compared with 7.5 percent annually during the previous decade. Growth slowed in the Middle East and North Africa as well.

China is an exception. Growth in spending during the first half of the 1990s rebounded from a period of stagnation during the last half of the 1980s. Things look a little better in Latin America, too, with growth in spending of 2.5 percent per year from 1991 to 1996, following little or no growth during the previous decade. But the recovery in Latin America seems fragile and is not shared widely throughout the region with many of the poorer (and smaller) countries in the region failing to experience any sustained growth in funding for the past several decades.

Spending by low-income countries (i.e., those countries with per capita incomes of less than $726 in 1996) grew fastest, so their combined share of the global total increased from 19 percent in 1976 to 28 percent in the mid-1990s. However, this trend is deceiving, reflecting the comparatively rapid growth of India and China, two large countries whose developments dominate the group average. In fact, the low-income countries as a group, excluding China and India, lost some ground. Their share of global agricultural R&D spending dropped from 8.7 percent in 1976 to 8.3 percent in 1996.

Funding mechanisms. Some innovations in funding methods have helped offset the slowdown in growth of public support for agricultural R&D. The main traditional funding method has been block grants to research institutes with little or no consideration of research priorities, research productivity, or research planning in general. In some countries public research institutes or agencies have tried to self-fund some of their research activity by commercializing their research operations or outcomes (for example, India, Indonesia, and even some CG centers). China also does this, partly motivated by a public-policy desire that research institutes get "in-tune" with market needs. This has had the unfortunate side-effect of distracting attention away from agricultural research and toward any activities that can raise funds (for example, the sale of bottled mineral water).

Research funding through commodity levies or "check-offs" is an important feature of some developed countries, such as Australia, and an element of R&D funding in some developing countries such as Uruguay, Zambia, South Africa, Colombia, Brazil, and Indonesia.[1] In Indonesia there is a long history of producer levies being used to fund research on plantation crops like oil palm because of their capacity to generate profits for those segments of the industry supporting the research through enhanced exports. Matching grants from governments seem rare in the financing of agricultural research worldwide. One exception is Australia, where the federal government matches dollars raised by farmers through levies on sales of the major agricultural commodities, with a cap on the government contribution of 0.5 percent of gross value of production. Another is the United States, where matching state funds are required to call forth a line of federal funds for the system of state agricultural experiment stations. Government matching grants for privately provided funds are also rare, although India provides an interesting example of innovative funding where the government offers matching funds for income generated by public research providers through commercialization of technology and services and contract research for the private sector

Competitive research grants (grants given on the basis of quality of project and the track record of researchers, which are common in developed countries) are becoming more widespread in the developing world (China, India, Indonesia, Korea, South Africa, Brazil, and Colombia, for example). These are generally seen as a mechanism that helps ensure "value for money" in the provision of research services, although they do have certain transaction costs and can involve rent-seeking costs (see, also Alston and Pardey 1999, 25–26). In many developing countries where alternative research providers are limited, it is hard to see that the potential benefits from making funds contestable are large enough to justify the additional costs.

Research intensities. Turning from absolute to relative measures of R&D investments, in 1995, developed countries as a group spent $2.64 on public agricultural R&D for every $100 of agricultural output, a sizable increase over the $1.53 they spent per $100 of output two decades earlier (Table 2). Since 1975, research intensities rose for the developing countries as a group, but unevenly. Despite having gained a greater absolute share of the developing world's total agricultural research spending, China's agricultural research intensity in the mid-1990s was no greater than in the mid-1980s. In other words, China's research spending grew, but its agricultural sector grew just as quickly. Although public research intensities appear to have grown throughout the rest of Asia and Latin America during the last decade of our data, Africa lost considerable ground, with research intensities now lower than in the 1970s.

---

[1] Facilitated by a 1994 revision to the Plant Breeders Rights Act, Australia has also introduced end point royalties for commercially sold crop varieties as described and discussed by Kingwell and Watson (1998).

Private versus public research. By the mid-1990s, about one-third of the $33 billion total investment in agricultural research worldwide was done by private firms, including those involved in providing farm inputs and processing farm products. But little of this research took place in developing countries (Table 3). The overwhelming majority ($10.8 billion, or 94 percent of the global total) was conducted in developed countries. In the less-developed countries, the private share of research was just 5.5 percent, where public funds are still the major source of support (and remain a significant source of support in rich countries, too, accounting for about half their total funding).

In addition, the research intensity gap between rich and poor countries is wide and growing. While public research intensities were four times higher in 1995 in rich countries than they were in poor ones, if total (that is, private and public) spending is considered, the gap grows to more than eightfold; with rich countries spending about $5.40 on agricultural R&D per $100 of agricultural gross domestic product (AgGDP), compared with poor countries spending about $0.66 on agricultural R&D per $100 of AgGDP.

Long-run perspectives

The eightfold difference in total research intensities is an indication of the present gap in generating new technologies between rich and poor countries. However, the size of the accumulated stock of knowledge—not merely the amount of investment in current research and innovative activity—provides a more meaningful measure of a country's technological capacity and a better account of cross-country differences in agricultural productivity. Science is a cumulative endeavor, with a snowball effect. Innovations beget new ideas and further rounds of innovation or additions to the cumulative stock of knowledge. The sequential and cumulative nature of scientific progress and knowledge is starkly illustrated by crop improvement. It typically takes 7–10 years of breeding to develop a uniform, stable, and superior crop variety, but in doing so, today's breeders build on an accumulation of knowledge built up by the breeders of yesterday. Breeding lines from earlier research are used to develop new varieties, so research of the distant past is still feeding today's research.

Figure 1 represents money measures of the stock of scientific knowledge based on research performed in the United States (assuming a baseline rate of depreciation of the knowledge stock of 3 percent per annum) and Africa (assuming the same 3 percent baseline depreciation rate as well as a rate of 6 percent per year, which is perhaps more realistic given the instability and lack of infrastructure for R&D throughout much of the region). Knowledge stocks in 1995—representing a discounted accumulation of research spending from 1850 for the United States and 1900 for Africa—were expressed as percentages of 1995 AgGDP to normalize for differences in the sizes of the respective agricultural sectors. The accumulated stock of knowledge in the United States was about 11 times more than the amount of agricultural output produced in 1995. In other words, for every $100 of agricultural output, there existed a $1,100 stock of knowledge to draw upon. In Africa, the stock of knowledge in 1995 was actually less than the value of African agricultural output that year. The ratio of the U.S. knowledge stock relative to U.S. agricultural output in 1995 was nearly 12 times higher than the corresponding amount for Africa. If a depreciation rate of 6 percent instead of 3 percent is used, the gap in American and African ratios is more than 14-fold.

Institutional Issues

Generating new ideas is difficult, transforming them into commercially viable technologies doubly so. Building effective science and technology capacity goes way beyond the funding and performance of R&D. It also involves building the capacity to commercialize and market the technologies, aspects that are coming under increasing scrutiny and regulation regarding their human health, phytosanitary, and environmental implications. Increasingly too, the agricultural sciences involve the bundling of a complex set of intellectual property rights (that encompass plant and utility patents, plant breeder rights, trademarks, and trade secrets, in addition to a myriad assignment of use rights subject to contract law).[2]

Some Fundamentals

Economists have long reported on the growth promoting effects of agricultural R&D and the sizable social payoffs to sustained public investments in research. However, the economic evidence on the

---

[2] Boettiger et al. (2004) discuss the intellectual property rights aspects and Josling, Roberts and Orden (2004) discuss the food regulation and trade issues, highlighting the international dimensions.

returns to research has failed lately to generate commensurate growth in public funding for agricultural R&D worldwide (although there are indications it may have ameliorated likely declines in public funding absent the evaluation evidence). Some of this may stem from misapprehensions about the roles of the public and private sectors; thinking, mistakenly, that private interests will fully offset a decline in public funding for research (notwithstanding the changing intellectual property incentives for agricultural R&D). These misapprehensions relate to the widely described underinvestment phenomenon that appears to bedevil agricultural R&D (see Alston and Pardey 2004 for a more complete exposition). Innovators often face appropriability problems—failing to fully reap the rewards of their research, which gives rise to a mismatch between the incidence of the benefits and costs of research. The appropriability problem confronts firms, industries, or countries who invest in R&D. Thus countries, for example, may invest less than the socially optimal amounts in R&D in the belief they can “free-ride” on research conducted in other countries (capturing some of the benefits from the research without having to pay for it). Moreover, as domestic policies generally change and affect agriculture, especially policies dealing with trade in agricultural inputs and outputs, there may be added policy confusion regarding the implications for the appropriate long-run public roles in agricultural R&D. What are the economic principles and market fundamentals shaping agricultural R&D capacity developments in the decades ahead?

Economic Principles

Efficiency versus equity aspects. Changes in government intervention can take many forms. Some commentators focus on increased funding of R&D from general government revenues, but this is only a part of the picture. Government can also act to change the incentives for others to increase their investments in private or public R&D (as well as 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, such as establishing levy arrangements; and
- encouraging individual or collective action through the provision of subsidies (or tax concessions) or grants in conjunction with levies.

Few of these of these policy choices can be resolved in principle. They require empirical evidence, obtained either informally or by structured (ex ante) economic evaluations of the relevant dimensions of the social benefits and corresponding costs of R&D.

One policy option is to change the scope of intellectual property rights, but these rights are applicable or enforceable only for certain types of inventions, and come at the cost that privately optimal prices may exceed socially optimal prices. Another option is for a government to delegate its taxing powers to an organization that represents the interests of a particular group in society, such as the Australian Research and Development Corporations (RDCs). An implicit assumption is that the managers of the RDC will choose a research portfolio that is consistent with the national interest, and this may be a reasonable assumption under a range of circumstances (e.g., see Alston, Freebairn and James 2004.

The RDC model may be seen as a reasonably fair and efficient way of achieving the economic efficiency objective of reducing the underinvestment in commodity research that would otherwise take place, and at least in the Australian context it would appear to have been successful from that point of view (see Alston, Harris, Mullen, and Pardey 1999). However, 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 (Pardey, Alston and Piggott 2004). In those cases where the fruits of invention are only partially appropriable, 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, the arrangements for financing 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 and inevitably they involve some judgment (formal or otherwise) about the economic payoffs to the research.

In fact much agricultural research is organized along industry or commodity lines and conducted in publicly managed agencies, albeit with increasingly diversified sources of support and new mechanisms to allocate research resources. For a national program of commodity research, the principal questions are: What should be the scope of the program's research portfolio, and which lines of research ought to be funded with which sources of support (be that block grants, levy-based funds, contract fee-for-service research, and so on)? There are both economic efficiency and equity dimensions to resolve. A simple economic efficiency rule is that the agency ought to allocate its funds so as to maximize the total benefits—but whose benefits (and costs) ought to be counted, benefits to all citizens or just national benefits to the industry? And within the industry, should we count benefits just to farmers or benefits accruing to processors and manufacturers as well? Should they count equally, or should farmer benefits get more weight. It is not trivial to separate the equity and efficiency issues.

Alston (2002) identified and discussed the vertical and horizontal dimensions of the distributions of costs and benefits of levy-funded research. First, consider the vertical dimension. One result from the literature is that, under commonly made assumptions, the benefits from research at one stage of a multistage production system will be distributed up and down the production-marketing chain in the same proportions as the cost of a levy collected at the same stage of production (e.g., see Alston and Mullen 1992). This result leads to the conclusion that it would be both fair and efficient to finance commodity-specific industrial research entirely using commodity levies so long as the research applies at the same stage as that where the levy was collected. Moreover, if the production technology across the stages of production is of a fixed-proportions nature, the research could apply at a different stage than the levy and yet the benefits would be distributed in proportion to the costs.

A breakdown of the congruence (or concordance) between the distribution of benefits from research and the distribution of the costs of a levy used to finance it could arise from several sources, however, including (1) variable factor proportions (possibly arising from variable proportions among multiple products each having different, possibly fixed, factor proportions), (2) research results applicable at a different stage of production than that where the levy is collected, (3) imperfect competition among processors or retailers, or (4) a non-parallel research-induced supply shift (the perfect matching of incidence of costs of a levy and benefits from research requires that the levy-funded research reduces average and marginal costs by the same amount per unit, such that the supply curve shifts down in parallel).

Since we cannot rule out these elements altogether, we cannot be sure that benefits will be distributed vertically in proportion to costs from levy-funded research, and this means that industry groups (such as those supporting the Australian Research and Development Corporations) are likely to opt for a rate of levy that is less than the social optimum, and to opt for a mix of research programs that gives up some economic efficiency in exchange for more equity. This observation provides a theoretical basis for (1) multiple levies to fund different lines of research collected at different stages in the system (on both equity and efficiency grounds), and (2) some matching grant support from the government (on efficiency grounds).

Next, consider the horizontal dimension. A commodity levy falls on all producers according to the amount of the commodity they sell, and in turn is passed on, up and down the marketing chain, depending on elasticities of supply and demand and so on, among middlemen and consumers according to the amounts of the commodity they buy. Every farmer bears a cost in proportion to their individual production regardless of whether they adopt new farming technology that is generated by the research funded by the levy. If prices were lowered as a result of the research, non-adopting farmers would be made worse off by both the new technology and the levy used to fund it.

One cause of horizontal inequity is when levy-funded research and extension is only narrowly applicable within the industry-applicable only in a certain geographical region or for certain types of farmers (e.g., irrigated versus non-irrigated or very large versus small, or for farmers eligible to participate in a particular extension program versus non-participants). An extreme form of this kind of inequity would be if levy funds were used to finance research that did not have any benefits within the industry but did benefit other members of the society—as for instance might occur if levy funds were used to finance research into environmental issues with a view to generating environmental benefits not confined to the industry or its participants. As for the problems with vertical market mismatches between the distributions of costs and benefits, perceived horizontal inequities are likely to give rise to under-funding overall (the group will choose a levy rate that is too low from the standpoint of economic efficiency alone, and will choose a sub-optimal mix of research programs, giving up some efficiency in exchange for greater perceived equity). This observation provides a theoretical basis for (1) multiple levies to fund different lines of research collected from different (horizontal) subsets of the industry (on both equity and efficiency grounds), defined spatially or in terms of the nature of their technology, and, perhaps (2) some matching grant support from the government (on efficiency grounds).

Spillovers. The horizontal inequities caused by research spillovers are pervasive, particularly spatial spillovers (although spillovers among firms, research disciplines, and industries are important as well). Spatial 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.

Alston (2002a) 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 sizeable 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. Evidently, because spillovers are so important, research resources have been misallocated both within and among nations. In particular, international spillovers contribute to a global under-investment in agricultural R&D that the existing public policies have only partly succeeded in correcting. The stakes are large because the benefits from agricultural technology spillovers are worth many times more than the investments that give rise to them.

Shifting Market Realities

The long lags between investing in R&D and realizing its economic consequences require forward-looking assessments for decisions dealing with scientific and technological capacities. The long lags also circumscribe the wisdom of depending too heavily on farmer-dominated research priorities which typically emphasize localized and more immediate problems over those with more expansive and long-term potential. A recent, comprehensive look at global agricultural commodity markets through to 2025 is instructive. Runge et al. (2003) conclude that:

- Fundamental shifts in diets are causing meat consumption in the developing world to rise, escalating demand for cereals for animal feed. As meat plays an increasing role, cereal consumption will slow. Raising cereal yields will continue to be important, but the efficiency of meat production will become equally significant.
- World cereal prices are likely to decline more slowly compared with historical trends, resulting from a gradual slowdown in the rate of cereal production growth.
- Cereal production will face land constraints and the area planted to cereals may fall in most regions except Latin America and Sub-Saharan Africa where additional land is still available. Yield growth must thus account for most production growth. In most countries and regions—Sub-Saharan Africa being the notable exception—a gradual slowdown in crop yields that began in much of the world during the early 1980s will pose major challenges.
- Land and water resource constraints will have major implications for sustainable food production and food security. Although many developed countries, particularly the United States, can expect only modest changes in agricultural yields resulting from climate change and should be able to adapt, developing countries—especially those in tropical areas—may have more difficulty.
- With demand for agricultural output projected to outstrip supply in many developing countries, fewer nations than ever will be self-sufficient in food production, and agricultural trade will grow to fill the gaps. China is likely to become a major net importer, as will East and South Asia and the Middle East

and North Africa. This will not necessarily produce global shortages, because agricultural exporters seem capable of keeping pace with the world's growing and urbanizing populations.

- Despite modest declines in real food prices and expanding world trade, food security for the poor will most likely improve only modestly in many regions and deteriorate in others without significant changes in national priorities. Sub-Saharan Africa will experience little improvement if current trends are simply carried forward. Slowly declining world food prices and buoyant international trade will coexist with continuing—and even rising—malnutrition in some regions, suggesting that trade liberalization is an insufficient basis for food security.

Additional to these developments, there is an equally potent set of institutional changes afoot regarding relationships among food production, wholesale, and retail operations. Partly as a consequence of liberalized investment opportunities (which has enabled foreign firms to more readily increase their investments throughout the developing world), and partly because of rapidly urbanizing populations and growing per capita incomes, the structure of food marketing is changing rapidly throughout much of the developing world. Retail food sales are quickly becoming the prevailing mode of delivery to consumers, with supermarkets and self-service convenience stores now dominant players in the agri-food economy (Reardon et al. 2003). For example, rough estimates are that 50-60 percent of Latin America's agri-food sales are now through supermarkets compared with just 10-20 percent a decade ago, with these developments being more pronounced in the larger, richer countries of the region (Reardon and Berdegué 2002). The top supermarket chains (including Wal-Mart, Royal Ahold, and Carrefour) account for an estimated 65 percent of supermarket sales in the region, so that private food quality standards and supply chain management decisions made by food retailers are having increasingly pervasive and profound affects on commodity choice, quality, and timing of delivery by the farm production sector.

Taken together, these "mega-trends" have important implications for on- and off-farm demands for technology, and the structure and likely sources of funds for the R&D required to develop and diffuse these technologies. Just as these shifting market realities reshape the incentives to innovate, they also have implications for the types of evaluation evidence that will best inform public and private investment decisions regarding agricultural R&D.

Economic Evaluations of R&D

The long time lags between investment in research and reaping rewards from invention are an important reason why there is under-investment in research. Even the most public-spirited politicians see less benefit in supporting research that develops a new crop variety in seven years than in subsidizing farmers directly today. Even when the long horizon of agricultural research is fully accounted for, the rates of return are still impressive. Comparing nearly 2,000 such estimates taken from 292 studies published since 1958, Alston et al. (2000) found that the average annual rate of return for all studies combined was an extraordinary 81 percent (70 percent for nominal rates of return and 77 for real returns after adjusting for inflation), although there is a large variation around this average (Table 4); U.S. government bonds, by comparison, yielded less than 6 percent in 2001.[3] Research is a particularly risky business. Many lines of inquiry just fail to pan out scientifically or economically. Nonetheless, the evidence is that the payoffs to investments in agricultural research are particularly high, even after factoring in the losers. Importantly, there is no evidence that the returns to R&D have diminished over time, so high current returns bode well for the future.

Whether they be ex post studies (assessing the impacts of past R&D spending) or ex ante assessments (investigating the likely impacts of research yet to be done), like it or not, the demand for economic evidence of the impact of R&D does not appear to be waning. Alston et al. (2001) identified 5 published studies of the rates of return to agricultural R&D in the 1960s growing to 179 studies in the 1990s (through to 1998). Many research agencies have regularized economic evaluations, presumably in response to the demands for accountability from those who fund R&D. For example, the Australian Center for International Agricultural R&D (ACIAR) has maintained an active economic evaluation unit for some time, while the CGIAR centers have invested considerable effort, individually and collectively, in formal evaluation exercises, with two standing panels of the CGIAR's Science Council now guiding

---

[3] Evenson, Waggoner and Ruttan (1979) and Echeverría (1990) provide earlier reviews of the literature.

the work. Even some funding agencies, like the Grains Research and Development Corporation (GRDC) of Australia has made ex ante assessments of proposed research a condition of funding the research.

Notwithstanding these trends, some are skeptical about the evidence, believing there has been a tendency to overstate the true payoffs to research. Alston et al. (2000) and Alston and Pardey (2001) lay out reasons why the evidence may be tainted, highlighting the selective use of studies of successful R&D (and ignoring the research or commercial failures) as representative of the *overall* returns to research, as well as a host of technical evaluation difficulties that arise even when the analyst is disinterested in the precise magnitudes of the result. It is inherently difficult to identify which research investment was responsible for a particular productivity improvement (or, conversely, which parts of the productivity benefits are attributable to a particular research investment)—ideally we not only want to attribute the productivity growth among research institutions at a point in time, but among these sources over time, including the distant as well as the recent past. Pardey et al. (2004) recently studied the implications of these attribution issues with new evidence for Brazil. During 1981-2003, varietal improvements in upland rice, edible beans, and soybeans yielded benefits of $14.8 billion in present value (1999 prices) terms. Attributing all of the benefits to Embrapa, a public research corporation accounting for more than half Brazil's agricultural R&D spending, the benefit-cost ratio would be 78:1. Under alternative attribution rules, the ratio drops to 16:1. A conclusion from this study, which would likely hold when reassessing much of the past evidence, is that even correcting for these overstatements, the rates of return have almost surely been much greater than the opportunity rate of return on government bonds

In recent years economists have developed formal models for the ex ante evaluation of research projects to assist decision makers responsible for allocating future funds to research (Alston, Norton and Pardey 1998; Pardey, Wood and Hertford 2004). These models are being used increasingly in more developed countries, but they seem not to be used on any systematic basis in many less-developed countries (unless there is a requirement to do so to secure donor funding). Similarly, the allocation of research funds against clearly articulated research priorities—as happens in some developed countries—is less common in the developing world. Notable exceptions are India, where there is now some movement in that direction, and Brazil's Embrapa, which is perhaps the greatest user of formalized approaches in research evaluation and priority setting (Pardey, Alston and Piggott 2004).

Conclusion

The institutional realties regarding the generation, use, and trade of new agricultural technologies have become increasingly complex. Moreover the scientific boundaries between agricultural, health and the other biological sciences are increasingly blurred and the spillovers among disciplines appear to have increased. Societies seem to increasingly question scientific outcomes in agriculture, and the sources of support, even for publicly managed R&D, have diversified.

An especially worrying development for those concerned especially with the plight of poor and hungry people in developing countries, is that rich countries are no longer as interested in simple productivity enhancements (increasing emphasis is being given to the post-farm and non-food aspects of agricultural technologies, as well as the food attributes demanded by wealthy consumers concerned about obesity, food quality, the environmental implications of agriculture). Even though there is no evidence to suggest that the world can afford to reduce its rate of investment in agricultural research, and every indication that we should invest more, we cannot presume that the rich countries of the world will play the same roles as in the past. The rise of modern biotechnology and enhanced intellectual property rights regimes mean that the types of technologies that were once freely accessible will be more difficult to access in the future, and the new technologies may not be as portable as in the past.

Thus, developing countries that in the past relied on technological spillovers from the North may no longer have that luxury available to them in the same ways or to the same extent. Moreover, setting aside a handful of countries, the developing-country gains in scientific and technological capacities achieved in the 1960s, 1970s and into the 1980s are no longer as evident, raising the prospect that a sizeable number of developing countries are becoming technological orphans.

All of these changes imply a demand for a greater investment in more detailed evaluations of agricultural R&D; and, as this paper has emphasized, evaluations that pay much more specific attention to the benefits attributable to specific sources of support and takes account of the various forms of research funding.

References

Alston JM and Pardey PG (2004). Developing-country perspectives on agricultural R&D: New pressures for self-reliance? in (Eds Pardey PG, Alston JM and Piggott RR). Agricultural R&D policy in the developing world. Washington DC: International Food Policy Research Institute, in preparation.

Alston JM, Freebairn JW, and James JS (2004). Levy-funded research choices by producers and society. Australian Journal of Agricultural and Resource Economics 48 (1), 33-64.

Alston JM and Pardey PG (2001) Attribution and other problems in assessing the returns to agricultural R&D. Agricultural Economics 25(2-3), 141-152.

Alston JM (2002a). Spillovers. Australian Journal of Agricultural and Resource Economics 48 (3), 315–346.

Alston JM (2002b).The "Domain" for levy-funded research and extension: General notions with particular applications to the Australian dairy industry. Connections: Farm Food and Resource Issues 3, 3–8. www.agrifood.info/Connections/Winter2002/alston.htm.

Alston JM, Chan-Kang C, Marra MC, Pardey PG, and Wyatt TJ (2000). A meta-analysis of the rates of return to agricultural R&D: Ex pede Herculem. IFPRI Research Report No. 113. Washington, DC: International Food Policy Research Institute.

Alston JM, Harris MS, Mullen JD, and Pardey PG (1999). Agricultural R&D policy in Australia in (Eds JM Alston, PG Pardey and VH Smith) Paying for agricultural productivity, Baltimore MD: Johns Hopkins University Press.

Alston JM and. Pardey PG (1999).The economics of agricultural R&D policy. In (Eds JM Alston, PG Pardey and VH Smith) Paying for agricultural productivity, Baltimore: Johns Hopkins University Press.

Alston JM Norton GW and Pardey PG (1998). Science under scarcity: Principles and practice for agricultural research evaluation and priority setting. Wallingford: CAB International.

Beintema NB (2004). Personal communication. Washington DC: International Food Policy Research Institute.

Boettiger S, Graff G, Pardey PG, van Dusen E, and Wright BD (2004). Intellectual property rights for plant biotechnology: International aspects." in (Eds. P Christou and H Klee) Handbook of plant biotechnology Chichester: John Wiley and Sons, forthcoming.

Echeverría RG (1990). Assessing the impact of agricultural research. in (Ed RG Echeverría) Methods for diagnosing research system constraints and assessing the impact of agricultural research, Vol. II, Assessing the impact of agricultural research. The Hague: ISNAR.

Evenson RE, Waggoner PE, and Ruttan VW (1979). Economic benefits from research: an example from agriculture, Science 205, 1101-1107.

Josling T, Roberts D and Orden D (2004) Food regulation and trade: Toward a safe and open global system. Washington DC: Institute for International Economics.

Kingwell R and Watson A (1998). End-point royalties for plant breeding: Cornucopia or coueism? Paper presented at the Australian Agricultural and Resource Economics annual conference, Armidale, January.

Pardey PG, Wood S and Hertford R. eds. (2005). Research futures: Projecting agricultural R&D potentials for Latin America and the Caribbean. Washington, D.C.: Regional Fund for Agricultural Technology (FONTAGRO) and International Food Policy Research Institute, book manuscript under preparation.

Pardey PG, Alston JM and Piggott RR eds (2004). Agricultural R&D policy in the developing world. Washington DC: International Food Policy Research Institute, in preparation.

Pardey PG, Alston JM, Chan-Kang C, Magalhães EC, and Vosti SA (2004). Assessing and attributing the benefits from varietal improvement research in Brazil. IFPRI Research Report No. 113. Washington, DC: International Food Policy Research Institute, forthcoming.

Pardey PG and Beintema NM (2001). Slow magic: Agricultural R&D a century after Mendel. IFPRI Food Policy Report. Washington, DC: International Food Policy Research Institute.

Reardon T, Timmer CP, Barrett CB, and Berdegué JA (2003). The rise of supermarkets in Africa, Asia and Latin America. American Journal of Agricultural Economics 85(5)(December): 1140-1146.

Reardon T and Berdegué JA (2002). The rapid rise of supermarkets in LAC: Challenges and opportunities for development, Development Policy Review 20(4)(September): 317-34

Runge C F, Senauer B, Pardey PG, and Rosegrant MW (2003). Ending hunger in our lifetime: Food security and globalization. Baltimore: Johns Hopkins University Press.

Table 1—Global public agricultural research expenditures, 1976–95

	1976	1985[a]	1995[a]
Expenditures	(*million 1993 international dollars*)		
Developing countries (119)[b]	4,738	7,676	11,469
Sub-Saharan Africa (44)	993	1,181	1,270
China	709	1,396	2,063
Asia and Pacific, excluding China (23)	1,321	2,453	4,619
Latin America and the Caribbean (35)	1,087	1,583	1,947
Middle East and North Africa (15)	582	981	1,521
Developed countries (34)	7,099	8,748	10,215
Total (153)	*11,837*	*16,424*	*21,692*

	1976–81	1981–86	1986–91	1991–96	1976–96
Annual growth rates	(*percent*)				
Developing countries (119)	7.0	3.9	3.9	3.6	4.5
Sub-Saharan Africa (44)	1.7	1.4	0.5	-0.2	1.5
China	7.8	8.9	2.8	5.5	5.2
Asia and Pacific, excluding China (23)	8.2	5.1	7.5	4.4	6.5
Latin America and the Caribbean (35)	9.5	0.5	0.4	2.9	2.5
Middle East and North Africa (15)	7.4	4.0	4.2	3.5	4.8
Developed countries (34)	2.5	1.9	2.2	0.2	1.9
Total (153)	*4.5*	*2.9*	*3.0*	*2.0*	*3.2*

Source: Pardey and Beintema 2001.

Table 2—Selected public research-intensity ratios, 1976–95

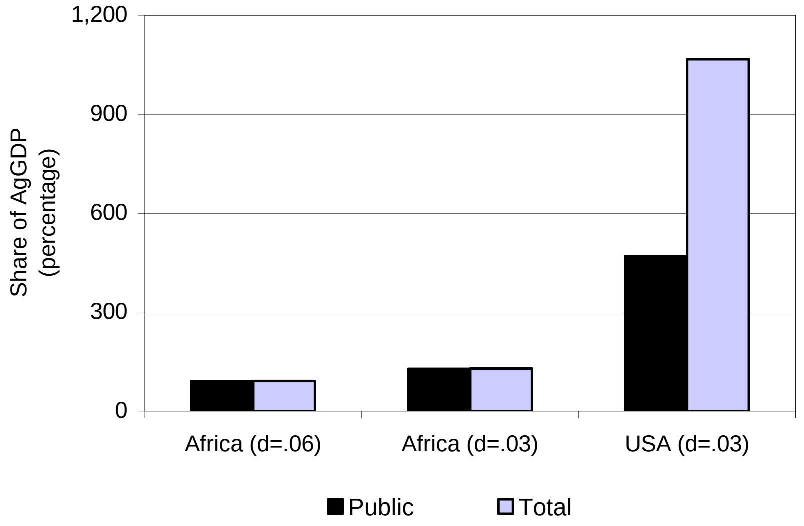
	Expenditures as a share of AgGDP			Expenditures per capita			Expenditures per economically active agricultural population		
	1976	1985[a]	1995[a]	1976	1985[a]	1995[a]	1976	1985[a]	1995[a]
	(*percent*)			(*1993 international dollars*)					
Developing countries	0.44	0.53	0.62	1.5	2.0	2.5	4.6	6.5	8.5
Sub-Saharan Africa	0.91	0.95	0.85	3.5	3.0	2.4	11.3	10.6	9.4
China	0.41	0.42	0.43	0.7	1.3	1.7	1.8	3.1	4.1
Other Asia	0.31	0.44	0.63	1.1	1.7	2.6	3.8	6.1	10.2
Latin America	0.55	0.72	0.98	3.4	4.0	4.6	26.0	36.0	45.9
Developed countries	1.53	2.13	2.64	9.6	11.0	12.0	238.5	371.0	594.1
Total	*0.83*	*0.95*	*1.04*	*3.3*	*3.8*	*4.2*	*12.9*	*15.3*	*17.7*

Source: Pardey and Beintema 2001.

Table 3—Estimated global public and private agricultural R&D investments, 1995

	Expenditures			Shares		
	Public	Private	Total	Public	Private	Total
	(million 1993 international dollars per year)			(percent per year)		
Developing countries	11,770	609	12,379	95.1	4.9	100
Developed countries	9,797	10,353	20,150	48.6	51.4	100
Total	*21,567*	*10,962*	*32,530*	*66.3*	*33.7*	*100*

Source: Pardey and Beintema 2001.



Source: Adapted from Pardey and Beintema 2001.

Figure 1—African versus American stocks of scientific agricultural knowledge

Table 4—Rates of return by commodity orientation

Commodity orientation	Number of observations	Rate of return		
		Mean	Minimum	Maximum
	(count)		(percent)	
Multicommodity	436	80.3	–1.0	1,219.0
All agriculture	342	75.7	–1.0	1,219.0
Crops and livestock	80	106.3	17.0	562.0
Unspecified	14	42.1	16.4	69.2
Field crops	916	74.3	–100.0	1,720.0
Maize	170	134.5	–100.0	1,720.0
Wheat	155	50.4	–47.5	290.0
Rice	81	75.0	11.4	466.0
Livestock	233	120.7	2.5	5,645.0
Tree crops	108	87.6	1.4	1,736.0
Resources[a]	78	37.6	0.0	457.0
Forestry	60	42.1	0.0	457.0
All studies	*1,772*	*81.2*	*–100.0*	*5,645.0*

Source: Alston et al. 2000.

a. Includes fishery and forestry.