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ABSTRACT

Over the past 50 years public agricultural research has contributed enormously to humanity, enabling the supply of food to grow faster than demand in spite of a rapidly growing population, income growth, and shrinking natural resources. Nonetheless, in many countries we see waning public support for agricultural R&D, especially in Africa, a diversion of research resources from farm productivity towards other agendas, and early warning signs of a slowdown in agricultural productivity. The world has continued to collectively underinvest in agricultural R&D because of domestic and international market failures associated with appropriability problems. Governments have failed to effectively address these problems, often doing too little, too late. This tragedy of the international commons may be getting worse. In the past, developing countries benefited considerably from technological spillovers from developed countries, but because of changes occurring in developed countries, spillovers from developed countries may not be available to developing countries in the same ways or to the same extent . In this article, the factors contributing to persistent global underinvestment in agricultural R&D are described from a developing-country perspective, estimates of agricultural R&D spending trends are presented, and incentive mechanisms for increasing rates of investment in agricultural R&D are described and assessed.

Agricultural R&D Policy: A Tragedy of the International Commons

In the past half-century, agricultural science achieved a great deal. Since 1960, the world's population has more than doubled, from 3.1 billion to 6.7 billion, and real per capita income has nearly tripled (U.S. Census Bureau 2008).[1] Over the same period, total production of cereals grew faster than population, from 878 million metric tons in 1961 to over 2,221 million metric tons in 2006, and this increase was largely due to unprecedented increases in crop yields (FAOSTAT 2008 and Pardey et al. 2007). The fact that the Malthusian nightmare has not been realized over the past 50 years is attributable in large part to improvements in agricultural productivity achieved through technological change enabled by investments in agricultural R&D.

Agricultural R&D is at a crossroads. The close of the 20th century marked changes in policy contexts, fundamental shifts in the scientific basis for agricultural R&D, and shifting funding patterns for agricultural R&D in developed countries. Even though rates of return to agricultural research are demonstrably very high, we have seen a slowdown in spending growth and a diversion of funds away from farm productivity enhancement. Together these trends spell a slowdown in farm productivity growth at a time when the market has begun to signal the beginning of the end of a half-century and more of global agricultural abundance. It is a crucial time for rethinking national policies and revitalizing multinational approaches for financing and conducting agricultural research. At a time when much of the world's attention is drawn to other global public goods—those associated with peace, security, communicable diseases, and climate change—we should not continue to neglect agricultural R&D.

In this paper, we describe factors that contribute to underinvestment in agricultural R&D, present estimates of agricultural R&D spending, and suggest alternative incentive mechanisms for increasing rates of investment in agricultural R&D.

Pervasive and Persistent Underinvestment

Although investment in agricultural R&D has yielded high returns and has played a major role in providing food and improving living standards for large and expanding populations, the world as a whole continues to invest too little in agricultural research. In many

[1] In 2000-based U.S. dollars, per capita income increased from $2,169 in 1962 to $6,389 in 2006 (World Bank 2007).

cases, individual research investors cannot appropriate all of the benefits from research that they fund, and consequently individuals will under-invest in R&D from a national perspective, a type of market failure. The same type of market failure occurs in an international context, where countries play the roles of individual firms to some extent. When research benefits can cross borders (i.e., research findings from one country can be adopted in another country, or consumers in one country can benefit from the lower prices caused by yield gains in another country), the domestic benefits will be smaller than the global benefits from research, creating an incentive for countries to under-invest in R&D from a global perspective.

Within nations, government intervention to correct this market failure mainly takes the form of providing public funds for R&D, or implementing policies that increase the appropriability of private research benefits. But the intervention has generally been too little or too late, and many countries have continued to underinvest in agricultural R&D, even from a national perspective. Among nations the problem may be more severe because the available mechanisms to address the international market failures are very limited. The world has continued to collectively underinvest in agricultural R&D because governments have failed to effectively address these domestic and international market failures.

Distinctive Features of Developing Countries

Domestic and international market failures have led to a major persistent gap between the socially desirable rates of investment in agricultural R&D and actual investments, particularly in developing countries. Five of their distinctive features help explain why the underinvestment problem is more pronounced in developing countries.

First, developing 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 costs of transport and communication, ill-functioning credit markets, and less-educated farmers are likely to reduce adoption rates of new inventions, decreasing the expected returns and increasing the risk of R&D investments. And, in rich countries, we might discount the issues of risk and capital costs as factors that discourage investment in invention, but in developing countries these factors might take on a different meaning, especially if capital markets do not function well.

Second, appropriability problems are more pronounced for the types of technological innovations best suited to much of developing country agriculture, such as improved self-pollinating crop varieties and farm management practices. Not surprisingly, these types of innovations have been comparatively neglected by the private sector, even in the richest countries. 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. The private sector has generally neglected varietal technologies except where the returns are appropriable, such as for hybrid seed (see Knudson and Ruttan 1988). Because of recent innovations in intellectual property protection, private firms in rich-countries are now finding it more profitable to invest in plant varieties. The same may be true in some developing countries, but not all countries have made comparable institutional changes. 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.

A third factor is that in many developing 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). One positive aspect of the recent increase in global grain prices is the positive signal it sends to farmers about investments in new agricultural innovations, provided that the price increases (a) are not appropriated by heavy-handed governments or private intermediaries and do pass back to farmers, and (b) are not offset completely by increases in the prices of the inputs (like seed, fertilizers and other agricultural chemicals) that typically embody these new technologies.

Price distortions, appropriability problems, and incomplete markets are important contributors to the problem of underinvestment in agricultural R&D in the private sector. Two additional features that are particularly pronounced in developing countries contribute to under-investment in the public sector. First, government revenues raised through general taxation may have a comparatively high opportunity cost in developing countries. In addition, many developing countries are characterized by under-investment 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). Like agricultural science, these other investments might also have high social rates of return.

Second, 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 support for agriculture—through price policies as well as R&D policies. In many developing countries, agriculture represents a much greater share of the total economic activity and per capita incomes are much lower. Hence, a meaningful investment in public agricultural research might impose a much more appreciable cost on individual citizens. The fact that this burden is felt now, while the payoff it promises may take a long time to come, and will be much less visible when it does, further diminishes the political appeal of supporting agricultural R&D.

The underfunding of agricultural R&D in developing countries is particularly alarming given (a) the continuing and substantive growth of populations, especially in the poorer parts of the developing world, (b) an increasingly scarce and deteriorating natural resource base, and (c) the pervasive pockets of hunger and poverty that persist in developing countries, in many cases despite impressive increases in national average productivity.

International Technological Spillovers

Underfunding of agricultural R&D in developing countries is clearly problematic, and the stage is set for the problem to worsen. In addition to the distinctive features of developing countries described above, the inadequacy of agricultural knowledge stocks may be exacerbated by changes occurring in developed countries. While the most immediate and tangible effect of the new technologies and ideas stemming from research done in one country is to foster productivity growth in that country, the new technologies and ideas often spill over and spur sizable productivity gains elsewhere in the world. In the past, developing countries benefited considerably from technological spillovers from developed countries, in part because the bulk of the world's agricultural science and innovation occurred in rich countries.[2] Increasingly,

[2] Developed countries have also benefited substantially from spillins of R&D done in or directed toward the developing world. Alston (2002a) reviewed work by economists in quantifying these benefits. For example, Brennan and Fox (1995) quantified the spillin benefits to Australia from selected CGIAR research and Pardey et al. (1996) the benefits to the United States from selected CGIAR research.

spillovers from developed countries may not be available to developing countries in the same ways or to the same extent.

Decreasing spillover potential is caused by several related market and policy trends in developed countries. First, the types of technologies being developed may no longer be as readily applicable to developing countries as they were in the past. Recently, developed country R&D agendas have been reoriented away from productivity gains in food staples toward other aspects of agricultural production, such as environmental effects, food quality, and the medical, energy, and industrial uses of agricultural commodities.[3] This growing divergence between developed country research agendas and the priorities of developing countries implies fewer applicable technologies that would be candidates for adaptation to developing countries.

Second, technologies that are applicable may not be as readily accessible because of increasing intellectual property protection of privately owned technologies and, perhaps, more importantly, the expanding scope and enforcement of biosafety regulations.[4] Different approaches may have to be devised to make it possible for countries to achieve equivalent access to technological potential generated by other countries. Third, those technologies that are applicable and available are likely to require more substantial local development and adaptation, calling for more sophisticated and more extensive forms of scientific R&D than in the past. In many instances developing countries may have to extend their own agricultural R&D efforts farther upstream, to more fundamental areas of the science. These new pressures for self-reliance in agricultural research are coming at a time when many developing countries, along with developed countries, are finding it difficult to sustain the current rates of investment in agricultural research.

[3] For example, Alston et al. (2008) report that only 59 percent of the $3,207 million of R&D conducted by the U.S. State Agricultural Experiment Stations (SAES) in 2004 was directly related to enhancing farm productivity, compared with 69 percent in 1975. Environmental (including forest- and fish-related) R&D has now grown to 14.1 percent of total SAES spending, basic crop and livestock genomic research accounted for an additional 4.5 percent, and post-farm (including food processing) research was 10.8 percent of the 2004 total.

[4] However, intellectual property rights may on balance increase access to and use of spillin innovations by increasing the incentives to locally adapt technology developed elsewhere and the incentives to invest in the marketing structures required to distribute and service new technologies. Wright et al. (2007) comprehensively discuss these incentive effects.

Economies of Size, Scale, and Scope in Agricultural R&D

In evaluating the extent of underinvestment in agricultural R&D and potential means of increasing investment, it is important to consider the economies of size, scale, and scope in knowledge accumulation and dissemination. For instance, if technological spillovers continue to be fairly available and accessible, as they have been in the past, it might not make sense for small, poor, agrarian nations to spend their scarce intellectual and other capital resources in agricultural science. However if spillins from developed countries decrease, developing countries will need to conduct more of their own research, but many nations may be too small to achieve an efficient scale in many, if any, of their R&D priority areas (e.g., Byerlee and Traxler 2001). Table 1, for example, shows that 40 percent of the agricultural research agencies in sub-Saharan Africa employed fewer than five full-time-equivalent researchers in 2000; 93 percent of the region's agricultural R&D agencies employed fewer than 50 researchers.

[**Table 1.** Size distribution of agricultural R&D agencies in Sub-Saharan Africa, 2000]

A particular problem for global efficiency in agricultural science is that we do not have sufficient institutions for financing and organizing research on a multinational basis so that economies of scale or scope may be exploited. One such institution is the Consultative Group on International Agricultural Research (CGIAR, or CG for short) system, which evolved through international efforts to address efficiency and equity aspects of the global underinvestment problem. In the mid-1940s, programs of internationally conceived and funded agricultural research were launched in an effort to overcome the biases against the development and diffusion of agricultural technologies suited for developing countries. Through the 1950s, these programs expanded as the Ford and Rockefeller Foundations placed agricultural staff in developing countries to work alongside scientists in national research organizations on joint-venture research. These efforts became the model for subsequent programs in international agricultural research, as they evolved into the International Rice Research Institute (IRRI) in the Philippines in 1960 and the International Maize and Wheat Improvement Center (CIMMYT) in Mexico in 1967. The further development of international agricultural research centers took place largely under the auspices of the CG system, a collective funding instrument established in 1971, as bilateral and multilateral donors bought into the model.

The CG system has captured the attention of the international agricultural R&D and aid communities because of its scientific achievements and its pivotal role in the Green Revolution. The main priorities of the CG system are to overcome, to some extent at least, the underinvestment problem and to help the food-poor. Over the past two decades, funds have been increasingly earmarked to support specific projects and research programs involving multiple centers and other research providers outside the CG system. In fact, the period after 1983 was one of a continuing decline in the share of unrestricted funds—down to 43 percent of the total in 2005 compared with a 1980s average of 80 percent (and a 1970s average of 88.3 percent for the precursor centers of the CG system).

As a result of increased earmarks, the system's mandate has broadened to include topics such as sustainability, food safety, nutrition, higher-quality food, and income distribution at the expense of agricultural productivity. Given that the research agendas of rich countries have evolved in the same direction, the shifting emphasis of the CG exacerbates the consequences of underfunding of productivity-oriented research by developing countries. From an efficiency perspective, it seems that the shift in research priorities may also be shifting the small resource base of the CG out of areas where it has a comparative advantage relative to public and private research in the national agricultural research systems of developed countries. In addition, with expansion of the number of centers and the broadening mandate, the management of the CG system has progressively become more complex, top-heavy, administratively burdensome, and expensive, notwithstanding some recent attempts to streamline operations. It seems that recent changes reflect a loss in efficiencies of size (as administrative fixed costs increase) and scope (as research agenda broadens beyond areas of expertise), and certainly reflect a reduction in the resources available for the more-traditional, productivity-enhancing investments.

The State of the Agricultural Sciences

In 2000, about $713 billion (international) dollars, or 1.7 percent of global GDP, was spent on *all* the sciences worldwide (Pardey, Dehmer and El Feki 2008).[5] A majority of the spending (80.6 percent), was by high-income countries. Patterns of R&D spending have changed significantly in the past two decades. Global spending on R&D nearly doubled in real

[5] This figure includes the total spending by public and private entities across all areas of science (i.e., including agricultural, medical, and engineering R&D, the information technology and social sciences, and so on).

(2000 international dollar) terms between 1981 ($383 billion) and 2000 ($713 billion). In addition, spending by developing countries has become much more concentrated. In 1981, China, India, and Brazil accounted for 25 percent of total research spending by developing countries. In contrast, in 2000, these three countries accounted for 42 percent of the developing country total.

Agriculture's share of total R&D is generally modest. In 2000, only 4 percent of total R&D spending by rich countries was oriented towards agriculture, whereas agriculture constituted an 8 percent share of total R&D spending among developing countries.[6] As a share of public R&D spending, agricultural has remained steady among the developed countries at around 7 percent in both 1981 and 2000. In contrast, among developing countries agriculture's share of public research spending declined from 22 percent in 1981 to 15 percent in 2000; albeit still more than double the corresponding rich-country share.

Worldwide, public investment in agricultural R&D increased by 35 percent in inflation-adjusted terms between 1981 and 2000, from an estimated $14.2 billion to $20.3 billion in 2000 international dollars (Table 2). It grew faster in developing countries (from $5.9 billion to 10.0 billion, a 53 percent increase), and the developing world now accounts for about half of global public-sector spending—up from an estimated 41 percent share in 1980.[7] However, developing countries account for about one third of the world's total agricultural R&D spending when private investments are included. Public spending on agricultural R&D is highly concentrated, with the top 5 percent of countries in the data set (i.e., 6 countries in a total of 129) accounting for approximately half of the spending, and the top 20 percent of countries accounting for 80 percent of spending (and smaller shares of agricultural GDP and population), as shown in Table 3.

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[6] In 2000 high-income countries spent $574.6 billion (international dollars) on R&D in total, of which $23.0 billion was spent on public and private agricultural research. In the same year developing countries spent $138.8 billion on R&D in total of which $10.7 billion was spent on public and private agricultural R&D. These shares are likely to understate the agricultural share of R&D since reported "agricultural R&D" figures typically omit research in basic biology, health, (bio-) informatics and other disciplines that have relevance for agriculture.

[7] As Pardey et al. (1992) described, these country and regional estimates of spending totals, shares, and rates of change are sensitive to the underlying national spending estimates as well as the procedures used to deflate and convert national spending estimates from the nominal local currency units in which they are typically compiled into the common currency unit reported here, 2000 international dollars. Aside from a revision to the public-sector series for Japan, the series used in this paper are the same as those reported in Pardey et al. (2006) except that the currency conversions were done using a revised purchasing power parity (PPP) series obtained from Martin (2008). As a consequence of these revisions, the estimated OECD share of the global agricultural R&D spending total increased from the 44.3 percent reported in Pardey et al. (2006) to the 50.6 percent share reported here.

[**Table 2**: Agricultural research expenditures by region, 1981 and 2000]

[**Table 3**: Concentration of public expenditures in agricultural research and development, 1981 and 2000]

The Asia and Pacific region has continued to gain ground, accounting for an ever-larger share of the world and developing country total since 1981 (25.1 percent of the world total in 2000, up from 15.7 percent in 1981). In 2000, just two countries from this region, China and India, accounted for 29.1 percent of all expenditure on public agricultural R&D by developing countries, a substantial increase from their 15.6 percent combined share in 1981. In stark contrast, sub-Saharan Africa continued to lose market share—its share fell from 17.9 percent of the total investment in public agricultural R&D by developing countries in 1981 to 11.9 percent in 2000 (Table 2).

Public Agricultural R&D Intensities

Developed countries as a group spent $2.36 on public agricultural R&D for every $100 of agricultural output in 2000: a sizable increase over the $1.62 spent per $100 of output in 1980, but about the same as the estimate of $2.33 per $100 of output in 1991 (Table 4). In contrast, the overall agricultural R&D intensity was static in developing countries. In 2000, developing countries spent just $0.50 on agricultural R&D for every $100 of agricultural output (in this case, agricultural R&D spending expressed as a percentage of agricultural gross domestic product, AgGDP).

[**Table 4**: Intensity of public agricultural R&D, 1981, 1991, and 2000]

The ratios between agricultural research spending and other country characteristics are also revealing. Developed countries spent $697 per agricultural worker in 2000, more than double the corresponding 1981 ratio, while developing countries spent just $8 per agricultural worker in 2000, an increase of less than 50 percent over the $6 per agricultural worker spent in 1981 (Table 4). These developed-developing country differences are, perhaps, not too surprising. A much smaller share of the developed country workforce was employed in agriculture, and the absolute number of agricultural workers declined more rapidly in developed countries than in developing countries.

Since everyone consumes agricultural outputs, agricultural R&D spending per capita is potentially interesting. Per capita spending rates were much lower among developing compared with developed countries: typically less than $3 per capita for developing countries (especially those in sub-Saharan Africa) whereas more than half of the developed countries invested more than $10 per capita in 2000. For developed countries, spending per capita rose substantially from 1981 to 1991 (a continuation of earlier trends documented by Pardey and Beintema 2001) but then fell between 1991 and 2000. This developed country reversal was driven mainly by developments in Japan, although only half the developed countries continued to increase their per capita spending on agricultural R&D throughout the 1990s. Spending per capita for developing countries increased from $1.81 per capita in 1981 to $2.13 in 2000. The outliers to this general trend are Latin America, where spending per capita decreased between 1981 and 1991, and sub-Saharan Africa, where agricultural R&D spending per capita has continued to decline since 1981.

Private Agricultural R&D Investments

The private sector has continued to emphasize inventions that are amenable to various intellectual property (IP) protection options such as hybrid crops, patents, and more recently, plant breeders' rights and other forms of IP protection. The private sector has a large presence in agricultural R&D, but with dramatic differences among countries. In 2000, the global total spending on agricultural R&D (including pre-, on-, and post-farm oriented R&D) was $33.7 billion. Approximately 40 percent was conducted by private firms and the remaining 60 percent by public agencies. Notably, 95 percent of that private R&D was performed in developed counties, where some 55 percent of total agricultural R&D was private, a sizeable increase from the 44 percent private share in 1981 (Table 2) This rich-country trend may well continue if the science of agriculture increasingly looks like the sciences more generally. In the United States, for example, the private sector conducted nearly 55 percent of agricultural R&D in 2000, compared with 72 percent of *all* R&D expenditures in that same year (NSF 2005). These increasing private shares reflect increasing industry R&D by the farm-input supply and the food processing sectors. Around the general trend was much country-specific variation. According to data underlying Pardey et al. (2006), Japan conducted a slightly larger share of its agricultural R&D in the private sector than the United States whereas Australia and Canada—both reliant on

privately developed, technology-intensive imports of farm machinery, chemicals and other agricultural inputs—had private-sector shares of agricultural R&D spending less than 35 percent in 2000.

In developing countries, only 6.4 percent of the agricultural R&D was private, and there were large disparities in the private share among regions of the developing world. In the Asia and Pacific region, around 9 percent of the agricultural R&D was private, compared with only 1.7 percent of the R&D throughout sub-Saharan Africa. The majority of private R&D in sub-Saharan Africa was oriented to crop-improvement research, often (but not always) dealing with export crops such as cotton in Zambia and Madagascar and sugarcane in Sudan and Uganda. South Africa carried out approximately half of the total measured amount of private R&D performed throughout sub-Saharan Africa.

The rich/poor country disparity in the intensity of agricultural research noted in Table 4 is magnified dramatically if private research is also factored in (Figure 1). In 2000, in developing countries as a group the ratio of total agricultural R&D spending to agricultural GDP was 0.54 percent (i.e., for every $100 of agricultural GDP, just 54 cents was spent on agricultural R&D). In developed countries the comparable intensity ratio was 5.28 percent, almost ten times greater.

[**Figure 1**: Public, private, and total agricultural R&D intensities, 2000]

Trends in Public Agricultural R&D Spending and Research Intensities

Similar to other measures of agricultural R&D spending, the patterns of spending growth are quite uneven. Figure 2 shows the average annual percentage change in public agricultural R&D spending (horizontal axis) and in public agricultural research intensities (calculated as the dollars of public agricultural R&D spending per $100 of agricultural GDP and shown on the vertical axis of Figure 2). There is one mark for each country for which spending and ARI data (or estimated data) were available, and the shape of the mark indicates the region. Larger marks of the same shape and shading represent average rates of growth in the regional aggregates of spending and public agricultural research intensities (i.e., they are essentially weighted averages of the country-specific growth rates). The table in the lower-right corner shows the distribution of countries in each regional aggregate among sections of the graph defined by the direction of change in ARI, public agricultural R&D spending, and agricultural GDP.

[**Figure 2**: Average annual rates of growth in public agricultural R&D spending and intensities, 1982-2000]

Adjusted for inflation, public spending on agricultural R&D grew (on an average annual basis) between 1981 and 2000 in 73 percent of the countries represented. However, spending growth was more prevalent among developing countries—with positive growth in 76 percent of developing countries, compared with 59 percent of developed countries. Spending also grew at higher rates, on average, in developing countries. The large black circle in Figure 2 reflects average growth in aggregate spending and research intensity in developing countries, and is positioned below and to the right of the large black square, which shows the corresponding measures for developed countries. Notably, the more recent rates of increase in real spending for all developing regions of the world failed to match the rapid ramping up of public agricultural R&D spending that Pardey and Beintema (2001) reported for the 1970s.

At first glance the rise in developed country agricultural research intensity ratios and the stagnant agricultural R&D intensities for developing countries appear to misrepresent the trends in spending, which showed that the growth in public investments in agricultural R&D in developing countries significantly outpaced the corresponding growth in investments in agricultural R&D in developed countries (i.e., average annual growth of 2.79 percent in spending by all developing countries combined versus 1.09 percent by developed countries). The relationship between growth in research intensities and spending also reflects changes in the size of the agricultural sectors (as measured in real 2000 international dollars). Because ARI is the ratio of spending to AgGDP, the rate of growth in ARI is equal to the rate of growth in spending less the rate of growth in AgGDP. Thus, for countries above the 45-degree line in Figure 2, growth in ARI was faster than growth in research spending, reflecting negative growth in inflation-adjusted AgGDP. Only 18 percent of developing countries experienced a contraction in agricultural GDP between 1981 and 2000, compared with 82 percent of developed countries. Therefore, even though spending grew at a faster rate in developing countries, ARI grew more slowly because the agricultural sector grew relatively quickly.

Figure 3 shows the changes in the corresponding growth rates from the 1980s to the 1990s. For instance, for countries represented in the upper-right section of the graph, both public agricultural R&D spending and public agricultural research intensities grew faster in the 1990s than in the 1980s. Again, the table in the lower-right corner shows the distribution of countries

in a region across sections of graph, where the sections are defined by the change in the growth rates (faster growth or slower negative growth denoted by two arrows up; slower growth or faster negative growth denoted by two arrows down).

The growth in spending for the Asia and Pacific region as a whole rebounded in the late 1990s from the slower growth rates observed for the 1980s. This was especially so in China and India during the period 1996 to 2000, in both instances reflecting government policies to revitalise public R&D and improve its commercialisation prospects, including linkages with the private sector (Fan et al. 2006; Pal and Byerlee 2006). Spending growth throughout the Latin American region as a whole was more robust during the 1990s than the 1980s, although the recovery was more fragile and less certain for some countries in the region (such as Brazil, where spending contracted at the close of the 1990s).

[**Figure 3**: Changes in average annual rates of growth in public agricultural R&D spending and intensities, from the 1980s to the 1990s]

Total investments in agricultural R&D in sub-Saharan Africa grew by less than 1 percent per between 1981 and 2000. Even more concerning is the fact that research spending fell in about 42 percent of the countries in the region. Investments in sub-Saharan Africa grew by less than 0.50 percent per year during the 1980s, but the rate of growth increased slightly in the 1990s to nearly 1 percent.

A notable feature of the trends was the contraction in support for public agricultural R&D among developed countries. While spending in the United States increased in the latter half of the 1990s, albeit more slowly than in preceding decades,[8] public R&D was substantially reduced in Japan (and also, to a lesser degree, in several European countries) towards the end of the 1990s. For developed countries as a whole and more than half of the developed countries included in the data set, both public agricultural R&D spending and research intensities grew more slowly in the 1990s than they did in the 1980s. These trends provide further evidence of those described above. Namely, support for publicly performed agricultural R&D among developed countries is being scaled back in some cases and slowing down in many others. This

[8] According to Alston et al. (2008) the rate of growth in U.S. public agricultural R&D spending rebounded somewhat in the 2000-2004 period.

points to a shifting emphasis from public to privately performed agricultural R&D, but also to a shift in government spending priorities.

Rich vs Poor Countries—A Growing Scientific and Knowledge Divide

Collectively these data point to a disturbing development: a growing divide regarding the conduct of (agricultural) R&D and, most likely, a consequent growing technological divide in agriculture. Only a few developing countries show signs of closing in on the higher amounts and higher intensity of investment in agricultural R&D typically found in the rich countries. Meanwhile, large numbers of developing countries are either stalling or slipping in terms of the amount spent on agricultural R&D, the intensity of investment, or both.

Table 5 makes more concrete the nature of that divide through a comparison of sub-Saharan Africa (a region consisting of 42 contiguous countries plus 6 island nations), India (a nation of 28 states and 7 union territories, 21 and 5 of them contiguous, respectively), and the United States (a nation of 50 states, 48 of them contiguous). The arable agricultural areas in these three parts of the world are similar, but Indian and African agriculture uses far fewer hectares per worker than in the United States. Moreover, land and labor are still dominant components of the cost of production in sub-Saharan Africa and India, whereas in the United States the combined cost share of these two inputs fell considerably during the past 50 years at least. Purchased inputs now constitute 38 percent of the total cost of production in U.S. agriculture, compared with 23 percent in 1949.

[**Table 5**: Agriculture and agricultural R&D indicators for the United States, India, and sub-Saharan Africa, 2000]

Not only is the structure of agriculture dramatically different, the structure of agricultural R&D is also markedly distinct. For most measures, the starkest contrast is between the United States and sub-Saharan Africa, with India usually somewhere in between. Africa has almost 30 percent more public agricultural researchers than the United States and 50 percent more than India, but the training of these researchers continues to lag well behind those in the United States (and well behind those researchers working elsewhere in the developing world). Approximately 25 percent of research full-time equivalents (FTEs) in sub-Saharan Africa have PhDs, compared with 100 percent in the United States and 63 percent in India.

African public agricultural research agencies are heavily skewed to the small end of the size distribution, with three quarters of these agencies employing fewer than 20 researchers, whereas one third of the public agencies in India and almost all the public agencies in the United States employ more than 100 researchers. The small size of many research agencies in India and particularly in sub-Saharan Africa makes it difficult to exploit the economies of scale that characterize the production of knowledge. Moreover, the lion's share of public research in the United States is now performed by universities, while the average university share is less than 20 percent in sub-Saharan Africa and approximately 45 percent in India.[9] Crucially, real spending per researcher in the United States is more than double its counterpart in India and more than four times its counterpart in sub-Saharan Africa; and the gap is growing. The long-run trend continues to be an increase in spending per scientist in the United States while inflation-adjusted spending in sub-Saharan Africa has shrunk to less than half what it was in 1981.

These measures suggest the immensity of the challenge of playing catch-up in countries like India, and the seeming impossibility of catching up in sub-Saharan Africa. The measures also underscore the need to transmit knowledge across borders and continents and to raise current amounts of funding for agricultural R&D while also developing the policy and infrastructure needed to accelerate the rate of knowledge creation and accumulation in the developing world over the long haul. Developing local capacity to carry forward findings will yield a double dividend: increasing local innovative capacities while also enhancing the ability of local research agencies to tap discoveries made elsewhere. It is also essential to increase complementary investments in primary, secondary, and higher education if the generation and accumulation of knowledge is to gain the momentum required to put economies on a path to lift people out of poverty.

In addition to these broad trends, other aspects of agricultural R&D funding that have important practical consequences are also of concern. For example, undue variability in R&D funding continues to be problematic for many developing-country research agencies. This is especially troubling for agricultural R&D given the long gestation period for new crop varieties and livestock breeds, and the desirability of long-term employment assurances for scientists and other staff (Pardey, Alston and Piggott 2006). Variability encourages an over-emphasis on short-

[9] Notably, government agencies accounted for over half the publicly performed agricultural R&D in the United States through to the mid-1900s, but the university share has grown steadily since then.

term projects or on projects with short lags between investment and outcomes, and adoption. It also discourages specialization of scientists and other resources in areas of work where sustained funding may be uncertain, even when these areas have high pay-off potentials.

Options for Government Action and Institutional Innovation

The available evidence generally supports the view that even with the existing, extensive government involvement, the world is investing too little in agricultural R&D—especially the developing world and especially in relation to staple food crops. Economists often call for governments to address this underfunding problem simply by increasing the total amount of government revenues committed to agricultural R&D. However, as first pointed out by Fox (1985), it costs society measurably more than a dollar to provide a dollar of general taxpayer revenues to finance public expenditures on agricultural R&D. The high opportunity cost of government funding helps explain the increasingly ineffective policy prescription and the persistence of the underfunding problem. Against that background, it seems appropriate to look for ways of developing alternative government interventions and institutions that are complementary with government funding. Ideally, these interventions and institutions would have a multiplier effect on government funding by drawing in funding from industry and encouraging private investment that might substitute for government spending.

A number of options can be and in many places are used instead of, or in combination with, general government funds to finance agricultural R&D undertaken in the public sector or the private sector. These include incentives for private innovation such as the provision of intellectual property protection or prizes to enhance inventor benefits or the provision of tax breaks or other mechanisms to offset private costs of research—in some senses substitutes for direct government spending on research. They also include institutions to encourage collective action by producers such as the use of commodity levies with matching government grants—with levy-based funding serving in some senses as a complement for government spending.

Protecting Intellectual Property

The private and public roles in agricultural R&D hinge largely, but not exclusively, on the degree to which the benefits from R&D are appropriable (i.e., accrue only to those who incurred the costs), and, relatedly, the distribution of the benefits. The nature and extent of

property rights surrounding agricultural innovations determine these appropriability aspects and, thereby, the incentives to invent and the consequences of those inventions. Thus the pace and focus of biological innovation in agriculture (and related industries), who pays for the R&D and how much, and, ultimately, the incidence of the costs and benefits of the research, are all affected by the form of the property protection afforded the results of the R&D.

Intellectual property rights (IPR) such as patents, trademarks, plant breeders' rights and copyrights are among the more prominent public policy responses intended to stimulate the creation and dissemination of inventions. The scope, economic costs and administrative processes of these different types of IPR vary, such that policy choices concerning which IPR to offer and practical decisions about which IPR to seek are governed by the nature of innovations. The patent system, which provides the innovator a monopoly right for a limited period in return for the disclosure of the innovation, has attracted much attention, partly because of its economic and political implications. In recent years, many countries have strengthened their patent systems as part of domestic initiatives to upgrade their national innovation systems (Mowery 1998), or to comply with international agreements.

The incentive effects of patents have long been recognized, as have the social costs of restricting the use of the patented product or process for the duration of the patent monopoly. Although a substantial minority has a different view (see, for example, Boldrin and Levine 2002), many and perhaps most economists support the inclusion of a patent system as part of a modern system of innovation and economic development. Protecting intellectual property in agriculture involves balancing access for the use of biological innovations in ways that reveal knowledge that can stimulate further invention, while conferring some degree of monopoly rights which generate revenue streams that reward successful innovation.

Exclusionary IP rights such as patents or plant breeders' rights are costly to obtain and to exercise. Notably, significant shares of agriculture in many developing countries involve subsistence or semi-subsistence cropping systems, with limited commercial opportunities to market seed and consequently less incentive to seek varietal rights, even if a legal option to do so existed. As a consequence of these realities, plant variety rights are still heavily biased to rich-country jurisdictions and heavily biased to higher-valued fruits, vegetables and ornamentals. The extent of formal intellectual property rights pertaining to plants is on the rise in selected developing-country jurisdictions—notably Brazil, China and India—but the vast majority of

crops in the vast majority of developing countries are still subject to little if any effective, legally sanctioned forms of intellectual property protection.[10]

National efforts to protect the intellectual property of biological innovations are increasingly being shaped and circumscribed by internationally agreed laws and conventions.[11] Some of these international initiatives (e.g., the 1993 Convention on Biological Diversity) seem to be driven more by concerns about the equitable distribution of the benefits from biological inventions (both in space and time—i.e., within the current population and across generations), than by concerns about concepts of economic efficiency. Other changes in international property-rights regimes are related to broader efforts to strengthen the property-rights regulations, which form part of the package of internationally agreed policies that underpin the trading arrangements enforced by the World Trade Organization. Indeed, the Marrakesh agreement signed by 131 countries to date, which was part of the Uruguay Round GATT/WTO trade agreement that came into force in January 1995, essentially committed all developed countries to have a functioning system of property protection for all types of inventions, including biological inventions, within one year (i.e., typically by 1996). Developing countries had by 2000 to become compliant with the agreement, and least-developed countries had until 2006 to enact such legislation. For product patents such as pharmaceutical patents, developing countries were not required to provide product patent protection until 2005. However, on June 2002, the Council for Trade-Related Aspects of Intellectual Property Rights adopted a decision that extended the deadline for least-developed countries to apply provisions pertaining to pharmaceutical patents until 2016.

Many of the details regarding the property-rights policies and laws covering biological innovations are far from settled and, if past history is any guide, will continue to evolve as political, economic, and scientific circumstances dictate. These details may vary markedly in their economic effects. Specifically, the form of the property protection may have significant

[10] For additional information on the developments concerning crop varietal rights in developing countries, see Koo et al. (2006), Louwaars et al. (2005) and Srinivasen (2005).

[11] Intellectual property rights only pertain to the jurisdiction in which they are awarded. To obtain patents or plant breeders' rights in multiple jurisdictions (countries) requires incurring the costs of applying for such rights in each and every jurisdiction. An exception to this situation arises in the case of European member countries of the Community Plant Variety Office (CPVO).

efficiency as well as equity effects, with important consequences for the structure of the R&D market in terms of the research that gets done, who does it, and who benefits.

Varietal Royalties

It is a longstanding and generally accepted practice in agriculture the world over to charge for the technical changes embodied in mechanical and chemical inputs. In contrast it is much less common to charge seed users (i.e., farmers) for new crop varieties. Partly this is because of historical precedent, where much of the crop-related R&D worldwide was funded from the public purse. Partly it reflects long-standing seed-saving and sharing practices by farmers that make it difficult for crop breeders to realize a return on their inventive effort, absent effective legal policies and practices. Royalty payments to plant breeders for the right to use new crop varieties are a specific institutional form of implementing and enforcing property rights over varietal innovations. In certain settings they also serve as a practical means for breeders to extract payment for their innovative effort. Both the protection of intellectual property and the increased benefits provide an incentive to invest in variety innovations.

The crop royalty schemes already in place vary markedly in their details. These details may well have significant long-run implications concerning who conducts and who pays for crop-improvement R&D, the types of crop technologies that are emphasized, and the uptake and use of crop varietal innovations. Developments in selected rich-country markets illustrate the range of crop royalty options that are feasible, especially in developing country markets as the legal and commercialization opportunities emerge. For example, the passing of the 1964 Plant Varieties and Seeds Act in the United Kingdom (amended under European law in 1994) means that only distinct varieties approved for National Listing can legally be sold in that country. At the point of seed sale these new varieties incur a royalty payment, collected by the British Society of Plant Breeders acting on behalf of crop breeders. Farmer-saved seed incurs a smaller royalty rate than certified seed and the royalty applies only to saved seed of the most recent varieties (BSPB n.d.).

A variant of this scheme is the technology-use fee charged by multinational agricultural biotechnology companies for the use of seeds that incorporate certain biotechnology traits (such as herbicide tolerance or resistance to corn borer or corn root worm). Typically the technology-use agreement allows for the one-time use of the purchased seed (thereby ruling out the legal use

of saved seed subject to these conditions of sale). Compliance rates with these technology-use agreements appear to be high in some countries such as the United States or Australia but have proved problematic in other countries, such as Argentina and Brazil, particularly for non-hybrid crops such as soybeans where seed saving and re-use is a practical and economic option (GAO 2000).

With the two schemes just described, farmers incur royalties at the point of seed sale. The 2002 passage of the Plant Breeders Rights Amendment Bill paved the way for an end-point royalty scheme in Australia. In this instance, based on a license agreement signed when they purchase the seed, farmers make a varietal declaration at the point of grain delivery and pay a royalty rate based on the tonnage of grain sold. The end-point royalties cover the costs of administering the scheme incurred by grain handlers and a general goods and services tax (GST), plus the innovator rents. Typically, 80 percent of the royalty passes back to the crop breeders, with any third-party equity in the R&D undertaking being paid out of the crop breeders' share. End-point royalty rates are set by the crop breeders and vary markedly by crop and by variety. Kingwell (2005) observed that rates set by public plant-breeding organizations are generally lower than those set by private firms.[12]

Farmers' compliance rates with the Australian end-point royalty scheme are estimated at around 80 percent (Wright and Pardey 2006).[13] For those crops (or sub-sectors) in those jurisdictions where the bulk of the crop is consumed on the farm where it is grown, or where the plant breeders' rights that underpin this payment system are lacking or ineffective, it is doubtful that such a payment system would be viable. However, farmers in developing countries may be willing to support such a scheme when it proves economic to do so, just as they have been willing to pay for hybrid corn and other productivity-enhancing inputs. The advantage of an end-point royalty scheme is that varietal developers and farmers share in yield risk. If the crop fails because of drought or hail or other factors, no royalty is paid under the end-point royalty scheme. In contrast, with an upfront payment scheme, farmers pay the same royalty regardless of the yields realized.

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[12] Kingwell (2005) noted that an A$8/mt royalty rate for an AgSeed Limited canola variety constituted less than 2 percent of the farm-gate value of the grain. Castillo, Parker and Zilberman (2000) observed that average royalty rates as a percent of sales for analogous R&D intensive output in engineering was around 6.3 percent and between 6.3 to 9.4 percent for a range of medical materials and services.

[13] Enright (2007) reported that in 2005/6 nearly 50 percent of the Australian wheat crop was sown to varieties subject to end-point royalties.

Prizes

Where property rights to invention cannot be made effective, or where doing so would be counterproductive (because the resulting price distortions and disincentives for adoption would be too expensive), inventors could be offered prizes for invention as an inducement to invest. Such institutions have a long and interesting history (e.g., as described by Wright 1983 and other papers cited therein). In recent years variations on these concepts have been proposed with particular relevance for research related to staple food crops in less-developed countries (e.g., Masters 2003 and 2005; Kremer and Zwane 2005). Prizes or research contracts may be effective in generating new innovations in certain circumstances (Wright et al. 2007). While these types of innovation incentives avoid monopoly pricing behavior and thereby increase consumer benefits, the problem remains of setting the right prize or contract support according to the value of the innovation.

Tax Breaks

A number of countries have tried tax concessions for private research, a form of joint-venture between public and private sectors. For instance, current R&D costs could be expensed at rates greater than 100 percent, or R&D capital costs could have accelerated depreciation rates. Tax concessions are generally blunt instruments. It is difficult to minimize the transfer effect, wherein (foregone) taxpayer funds merely substitute for private R&D investments that otherwise would have taken place. In addition, it is difficult to design tax concessions that discriminate among alternative forms of research (i.e., additional investments in on-going lines of research by existing firms versus investments in new research by existing firms versus new, start-up firms; or more strategic kinds of R&D with more spillover potential versus applied research) or among providers of research (e.g., local versus foreign firms). A blunt tax concession aimed at stimulating new research done locally could simply cause research funds being used elsewhere to be diverted to take advantage of the local tax breaks (Industry Commission 1995). On the other hand, while tax-breaks involve some transactions costs (in terms of the paperwork involved, auditing costs, and the like) it is a funding approach that is comparatively inexpensive to administer, at least in those places (e.g., many developed countries) where the tax system is well-equipped for such purposes.

Collaborative Approaches to Innovation Development

More recently, "open source" approaches to developing software products using, for example, Apache and Linux have attracted much attention as a collaborative approach to innovation development (Benkler 2004). Explanations for the incentive to reveal one's innovations in an open source context include (a) the "career concerns" of participants who expect to gain indirectly from the reputational effects of involvement in open source (Lerner and Tirole 2002), (b) the efficiency of a decentralized approach to debugging a system with millions of potential configurations (Bessen 2004), and (c) the intrinsic motivation of delight in solving an intellectual challenge and the reward of recognition by one's peers. Some people argue that this approach offers a way of reconciling the public interest in minimizing restrictions on access to new technologies (Lerner and Tirole 2005), and thus similar innovation systems have been suggested in other areas of industry.

The recent Biological Innovation for Open Society (BIOS) initiative arising out of CAMBIA is an attempt to initiate open-source development of key enabling technologies for agricultural biotechnology using licensing strategies inspired by the open source movement in software (Nature 2004). The Public-Sector Intellectual Property Resource for Agriculture (PIPRA) initiative is an attempt by public and nonprofit researchers to provide mutually consenting parties reciprocal access to their proprietary technologies, while also making such technologies available to developing-country researchers in ways that do not relinquish licensing options and potential royalty revenues from private-sector entities in developed countries (Graff et al. 2003; Atkinson et al. 2003; Delmer et al. 2003).

Public- versus Collective-Goods Perspectives

Agricultural R&D may be a public good in the sense of (at least partial) non-excludability and non-rivalness, but this does not mean that everybody in the nation benefits and it does not mean that everybody in the nation should pay. Indeed, for many types of research and common commodity market conditions, commodity prices are not affected, and the benefits are confined to those producers who adopt the resulting technology. In other cases, the adoption of technology that leads to improvements in productivity leads to lower commodity prices with benefits distributed between consumers of the commodity and producers who adopt the new technology, perhaps partially at the expense of producers who do not adopt (or are slow to adopt)

the new technology. Sometimes the lower prices are transmitted to producers and consumers in other countries, and sometimes foreign producers can adopt the new technology, adding further complications to the picture of the distribution of the benefits from the new technology. Citizens who do not consume or produce the commodity in question are not beneficiaries even though they may be taxpayers and asked to support the R&D.[14]

Consequently, rather than public goods, many types of agricultural R&D may be better thought of as collective goods, for which the relevant collection of beneficiaries may be a group of producers (and consumers) of a particular commodity coming from a particular region. Economic efficiency (along with some concepts of fairness) is likely to be promoted by funding research so that the costs are borne in proportion to the benefits to the greatest extent possible. This can be accomplished by choosing funding arrangements that reflect the geographic focus and the commodity orientation of the research. Thus, different agricultural R&D programs and projects may call for different funding arrangements—for instance, at the state, national, or multinational level or using different mechanisms. However, a more complete accounting of social costs and benefits should allow for economies of size, scale, and scope in research (e.g., see Jin et al. 2005) as well as various types of political costs, administrative costs, and transaction costs associated with having different research organizations with overlapping jurisdictions. This more complete accounting is likely to imply a smaller number of different funding arrangements than would be implied otherwise.

When research benefits are contained entirely within an industry, a natural option is to develop an institutional arrangement to enable the industry to raise its own research funds. Where research costs and benefits are industry-specific, there may be still problems of intra-industry distribution of benefits and costs and spillovers that lead to distortions in the allocation of industry-based research funds among research topics (e.g., Alston 2002b; Alston, Freebairn and James 2003), justifying a role for the government. And, once other (extra-industry) spillovers are present or there are other sources of a mismatch between industry and national optima, there are additional reasons for government involvement—possibly both in supplementing the funding and directing the R&D effort (e.g., Alston, Freebairn and James 2004).

[14.] Alston, Norton, and Pardey (1995) elaborate at length on the determinants of the distribution of benefits from research among producers, consumers, middlemen, foreigners, and so on.

Commodity Levies and Matching Grants

When the government gives producers the statutory authority to set up an institution the problems of non-excludability and non-rivalry are ameliorated. A greater use of levy funding could enhance economic efficiency in three ways. First, industry funding is a potential complement to other sources of funds which, as a practical matter, are likely to continue to leave total funding inadequate from the viewpoint of both the industry and the nation. Second, from the point of view of raising funds in the least-cost way, commodity levies are likely to be a relatively efficient (and fair) tax base. Third, in relation to allocating the funds efficiently, industry funding arrangements can be organized to provide incentives for efficient use of levy funds and other research resources. Incentives for industry to adopt a levy-based funding arrangement may be enhanced by an appropriate system of intellectual property protection. Commodity-specific levy arrangements are most applicable for commodity-specific R&D of a relatively applied nature.

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. When a combination of industry levy funds and general revenues is used to finance public or privately executed R&D, there is a clear case for government involvement in the administration, management, and allocation of those funds to ensure that the public interest is adequately considered. It is important to understand that industry levy funding is not to be regarded solely as a producer "self-help" arrangement in which producers collectively fund research on their own behalf and to serve their own ends. Consumers and taxpayers are also affected and have a legitimate interest in such enterprises.

When spillovers from industry-funded research flow beyond the industry to the general community, the situation is likely to be more complicated. In the case where research results exhibit classic "public good" characteristics—that is, both non-rivalry and non-excludability are severe—then the research should be publicly funded, although it may still be efficient for it to be provided under contract by the private sector. When a significant proportion of the benefits accrue to an industry, the research has both public and (collective) private good characteristics, it is appropriate to fund the research from both public and private sources.

Questions arise about whose objectives will determine the setting of the levy and the allocation of the resources, and what is the appropriate rate of matching government grant. Alston, Freebairn and James (2003, 2004) analyzed the factors that influence the rate of matching support appropriate to give a producer board incentives that would be compatible with the interests of the nation. They showed that there are no simple rules, even in a relatively stylized setting; but even so in many cases a simple rule such as 1:1 matching would be likely to result in enhanced economic efficiency compared with zero matching support. In practice, arrangements of this type are more likely to be embraced by the industry if producers have the major say in setting the research agenda and if the rate of matching government support is higher. At the same time, the greater is the rate of matching government support, the more likely is the government to want to set the agenda.

Other complications arise when we recognize that within any group of producers interests will vary because the applicability of research findings will vary, and the distribution of benefits and costs among producers within a collective action program may present obstacles to fairness and efficiency that have implications for both the amount of funding raised and the allocation of the funds among alternatives (Alston 2002b discusses some of these factors). Because some research has both public and private good components, the underinvestment may also be "relative" in the sense that the mix of research may be skewed. Designing a completely fair and efficient commodity levy arrangement for financing research is not simple, and perhaps this helps to understand the limited use of these arrangements in most countries in the past.[15]

These drawbacks notwithstanding, a small but increasing number of countries has adopted such arrangements for financing and conducting agricultural research, and in some places they are used extensively—notably Australia and Uruguay. Other places appear to be showing some interest in increasing their use of this option—for instance Canada and California—as a way of buttressing an otherwise stagnant or shrinking supply of public agricultural research funds. For the most part, however, these policies are little used in developing countries, though potential benefits from adopting levy-based research funding methods might be greatest for developing countries given (a) that general government funding is

[15] In most countries, such arrangements are used much more extensively as a mechanism for financing commodity promotion programs than agricultural R&D. A likely explanation for this fact is that effective generic promotion programs tend to enhance demand faced by all producers and immediately, whereas research takes longer and only adopters benefit.

very limited and has a high opportunity cost, (b) the limited interest of the private sector, and (c) reduced prospects of applicable agricultural technological spillovers from developed countries, compared with the past. But the question is more complicated, since many of the relevant commodities are staples, and they are mostly consumed within the household that produced them rather than traded.[16] Thus there may be significant practical, political, and economic reasons that militate against the use of levy-based funding for research for at least some commodities produced in developing countries.

Conclusion

With headlines in 2008 of surging food prices, historically low global stocks of food staples worldwide, and civil unrest over access to food, the temptation will be to resort to quick policy responses, perhaps thinking that short-term responses will be sufficient. Certainly some share of the spike in food prices is attributable to recent developments, including surging demand for corn for ethanol production and drought-induced shortfalls in the supply of wheat from Australia and elsewhere. But other, structural shifts are at play, affecting the global demand for and supply of food in ways that will require sustained attention, irrespective of whether rains return to presently parched fields or alternative feedstocks are developed to reduce the demand for grain for production of biofuels. The structural shifts in the demand for food are on-going and long-term. Global population has more than doubled in the past four decades to 6.7 billion, and is projected to increase by a further 3 billion by 2050. Rising per capita incomes, especially throughout East and South Asian countries, amplify the population effects and will continue to put upward pressure on food prices for decades to come.

In the past 50 years, productivity growth played a crucial role in increasing food supplies, enabling agriculture to more than keep pace with the growing demand for food fuelled by population growth and per capita income growth, and helping to reduce the global problems of chronic hunger and poverty. A fundamental driver of this productivity growth has been the technical changes from improved inputs such as seeds, fertilizers and production practices that

[16] Kangasniemi (2002) discusses the use of commodity levy schemes to fund R&D in sub-Saharan Africa. Notably all the examples cited, specifically tea and coffee research in Kenya, sugar, tobacco and cotton research in Zimbabwe, and tea research in Tanzania, involve producer levies on export-oriented cash crops, where local farmers adopting the results of R&D are likely the primary beneficiaries of the levy-financed research, subject to the spillover and within industry distributional aspects discussed above.

stem directly from investments in R&D. The next 50 years will call for even more of the same kinds of technological changes and productivity growth. This will be necessary not just to meet the present demand and to reduce the chronic hunger experienced by an estimated 854 million people worldwide (Wiesmann et al. 2007), but also to address the future growth in demand for farm commodities for food and fuel in the face of a shrinking natural resource base. The lags between investing in R&D and realizing a return from that investment are long, matters of decades not months or years. Getting the policies right to stimulate the required public and private provision of new agricultural technologies requires a commensurate long-term timeframe.

The recent reconfiguration of global food markets may prompt some governments to rethink their national and multinational agricultural R&D policies. Governments can take some initiatives in national agricultural R&D policy, such as enhancing IP and tailoring the institutional and policy details of IP protection to best fit local circumstances; increasing the total amount of government funding for their national agricultural R&D systems; introducing institutional arrangements and incentives for private and joint public-private funding; and improving the processes by which agricultural R&D resources are administered and allocated.

Coupling these national initiatives with appropriate multilateral responses will be essential if the right amount and mix of agricultural R&D is to be undertaken to address the international commons problems broached in this paper. Sustaining the policy attention over the decades will also be necessary for R&D to realize its agricultural productivity potentials, and this will require a significant departure from the policy and (multilateral) funding processes in play over the past several decades. The rapid rise in global food prices now being experienced worldwide and the expectation that these higher prices will prevail for years to come may yield some substantial, persistent and pervasive benefits worldwide if it prompts policy makers to take appropriate action to reform agricultural R&D policy with proper attention to the global commons and the long run.

References

Alston, J.M. and P.G. Pardey. "Market Distortions and Technological Progress in Agriculture." *Technological Forecasting and Social Change* 43(3/4) May/June (1993): 301-319.

Alston, J.M., G.W. Norton, and P.G. Pardey. *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Ithaca: Cornell University Press, 1995 (reprinted in soft cover by CAB International 1998).

Alston, J.M. "Spillovers." *Australian Journal of Agricultural and Resource Economics* 48(3)(2002a): 315–346.

Alston, J.M. "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(August 2002b):3-8. http://www.agrifood.info/connections/winter_2002/Alston.html

Alston, J.M., J.W. Freebairn, and J.S. James. "Distributional Issues in Check-off Funded Programs." *Agribusiness: An International Journal* 19(3)(Summer 2003): 277-288.

Alston, J.M., J.W. Freebairn, and J.S. James. "Levy-Funded Research Choices by Producers and Society." *Australian Journal of Agricultural and Resource Economics* 48(1)(March 2004): 34-64.

Alston, J.M., M.A. Andersen, J.S. James, and P.G. Pardey. *Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending*. Monograph. St Paul and Davis: University of Minnesota and University if California, Davis, 2008 (in preparation).

Atkinson, R.C., R.N. Beachy, G. Conway, F.A. Cordova, M.A. Fox, K.A. Holbrook, D.F. Klessig, R.L. McCormick, P.M. McPherson, H.R. Rawlings III, R. Rapson, L.N. Vanderhoef, J.D. Wiley, and C.E. Young. "Public Sector Collaboration for Agricultural IP Management." *Science* (301)(July11 2003): 174-175.

Beintema, N.M. and G. Stads. *Investing in Sub-Saharan African Agricultural Research: Recent Trends*. 2020 Africa Conference Brief No. 8. Washington DC: International Food Policy Research Institute, 2004.

Benkler, Y. "Commons-Based Strategies and the Problems of Patents." *Science*, 305(August 20, 2004): 1110-1111.

Bessen, J. "Open Source Software: Free Provision of Complex Public Goods." Cambridge, MA: Massachusetts Institute of Technology, 2004.

Boldrin, M. and D. Levine. “The Case Against Intellectual Property.” *American Economic Review* 92(2)(2002): 209-212.

Brennan, J.P., and P.N. Fox. *Impact of CIMMYT Wheats in Australia: Evidence of International Research Spillovers*. Economics Research Report No. 1/95. Wagga Wagga, Australia: New South Wales Department of Agriculture, 1995.

Byerlee, D., and G. Traxler. “The Role of Technology Spillovers and Economies of Size in the Efficient Design of Agricultural Research Systems.” Chapter 9 in J. M. Alston, P. G. Pardey, and M. J. Taylor, eds. *Agricultural Science Policy: Changing Global Agendas*, Baltimore: Johns Hopkins University Press, 2001.

Castillo, R., D. Parker and D. Zilberman. “Offices of Technology Transfer and Privatization of University Discoveries.” Unpublished Working Paper, Department of Agricultural and Resource Economics, Berkeley: University of California, Berkeley, May 2000.

Delmer, D.P., C. Nottenburg, G.D. Graff, and A.B. Bennett. “Intellectual Property Resources for International Development in Agriculture.” *Plant Physiology*, 133(2003): 1666-1670.

Enright, T. Personal Communications as chairman of GRDC Board. Canberra: Grains Research and Development Corporation, 2007.

Food and Agriculture Organization of the United Nations. *FAOSTAT*. Retrieved June 5, 2008, from http://www.faostat.fao.org/, 2008.

Fan, S., K. Qian, and X. Zhang. “China: An Unfinished Reform Agenda.” Chapter in P.G. Pardey, J.M. Alston, and R.R. Piggott, eds. *Agricultural R&D in the Developing World: Too Little, Too Late?* Washington D.C.: International Food Policy Research Institute, 2006.

Fox, G.C. “Is the United States Really Underinvesting in Agricultural Research?” *American Journal of Agricultural Economics* 67 November (1985): 806-812.

GAO (United States General Accounting Office). *Biotechnology: Information on Prices of Genetically Modified Seeds in the United States and Argentina*. Washington D.C.: General Accounting office, January 2000.

Graff, G.D., S.E. Cullen, K.J. Bradford, D. Zilberman, and A.B. Bennett. “The Public-Private Structure of Intellectual Property Ownership in Agricultural Biotechnology.” *Nature Biotechnology* 21(9)(2003): 989-995.

Industry Commission. *Research and Development–Volume* 1. Canberra: Australian Government Publishing Service, 1995.

Jin, S., S. Rozelle, J.M. Alston, and J. Huang. "Economies of Scale and Scope and the Economic Efficiency of China's Agricultural Research System." *International Economic Review* 46(3) August (2005): 1033-1057.

Kangasniemi, J. "Financing Agricultural Research by Producer Organizations in Africa." Chapter 5 in D. Byerlee and R.G. Echeverria, eds. *Agricultural Research Policy in an Era of Privatization*. Wallingford: CAB International, 2002.

Kingwell, R. "Institutional Change and Plant Variety Provision in Australia." *Australasian Agribusiness Review* 13(2005). Available on-line at http://www.agrifood.info/review/2005/.

Knudson, M.K. and V.W. Ruttan. "Research and Development of a Biological Innovation: Commercial Hybrid Wheat." *Food Research Institute Studies* 21 (1)(1988): 45-68.

Koo, B., P.G. Pardey, K. Qian, and Y. Zhang. "An Option Perspective on Generating and Maintaining Plant Variety Rights in China." *Agricultural Economics* 35(2006): 35-48.

Kremer, M. and A.P. Zwane. "Encouraging Private Sector Research for Tropical Agriculture." *World Development* 33(1)(2005): 87-105.

Lerner, J. and J. Tirole. "Some Simple Economics of Open Source." *Journal of Industrial Economic*s 50 (2002): 197-234.

Lerner, J. and J. Tirole. "The Economics of Technology Sharing: Open Source and Beyond." *Journal of Economic Perspective* 19(2)(2005): 99-120.

Louwaars. N.P., R. Tripp, D. Eaton, V. Henson-Apollonio, R. Hu, M. Mendoza, F. Muhhuku, S. Pal and J. Wekundah. *Impact of Strengthened Intellectual property Rights Regimes on the Plant Breeding Industry in Developing Countries*. Wageningen: Wageningen UR, 2005.

Martin, W.J. Personal Communication. Washington D.C.: World Bank, 2008.

Masters, W.A. "Research Prizes: A New Kind of Incentive for Innovation in African Agriculture." *International Journal of Biotechnology* 7(1/2/3)(2005): 195-211.

Masters, W.A. "Research Prizes: A Mechanism to Reward Agricultural Innovation in Low-Income Regions." *AgBioForum* 6(1&2)(2003): 71-74.

Mowery, D.C. "The Changing Structure of the US National Innovation System: Implications for International Conflict and Cooperation in R&D Policy." *Research Policy* 27(1998): 639-654.

Nature. "Open-Source Biology." *Nature* 431(September 30, 2004): 491.

NSF (National Science Foundation). *National Patterns of Research and Development Resources: 2003.* NSF 05-308. Arlington, Virginia: National Science Foundation, Division of Science Resources Statistics, 2005.

Pal, S. and D. Byerlee. "India: The Funding and Organization of Agricultural R&D Evolution and Emerging Policy Issues," Chapter in P.G. Pardey, J.M. Alston, and R.R. Piggott, eds. *Agricultural R&D in the Developing World: Too Little, Too Late?* Washington D.C.: International Food Policy Research Institute, 2006.

Pal, S. Personal Communication. New Delhi: National Centre for Agricultural Economics and Policy Research, June 2008.

Pardey, P.G., J. Roseboom, and B.J. Craig. "A Yardstick for International Comparisons: An Application to National Agricultural Research Expenditures." *Economic Development and Cultural Change* 40(2)(January 1992): 333-349.

Pardey, P.G., J.M. Alston, J. Christian, and S. Fan. *Hidden Harvest: U.S. Benefits from International Research Aid*. Food Policy Report. Washington, D.C.: IFPRI (International Food Policy Research Institute), 1996.

Pardey, P.G. and N.M. Beintema. *Slow Magic: Agricultural R&D a Century After Mendel*, IFPRI Food Policy Report. Washington, D.C.: International Food Policy Research Institute, October 2001.

Pardey, P.G., J.M. Alston, and R.R. Piggott, eds. *Agricultural R&D in the Developing World: Too Little, Too Late?* Washington D.C.: International Food Policy Research Institute, 2006.

Pardey, P.G., N.M. Beintema, S. Dehmer, and S. Wood. *Agricultural Research: A Growing Global Divide?* IFPRI Food Policy Report. Washington, D.C.: International Food Policy Research Institute, 2006.

Pardey, P.G., J. James, J. Alston, S. Wood, B. Koo, E. Binenbaum, T. Hurley and P. Glewwe. *Science, Technology and Skills.* Background Paper for the World Bank's *World Development Report 2008.* St. Paul, Rome and Washington D.C.: University of Minnesota, CGIAR Science Council and World Bank, 2007.

Pardey, P.G., S. Dehmer, and S. El Feki. *Science Spending—A World Divided?* International Science and Technology Practice and Policy (InSTePP) Center. St Paul: University of Minnesota, 2008 (in preparation).

Runge, F.C., B. Senauer, P.G. Pardey, and M.W. Rosegrant. *Ending Hunger in our Lifetime: Food Security and Globalization*. Baltimore: John Hopkins University Press, 2003.

Schultz, T.W. "On Economics and Politics of Agriculture." In *Distortions in Agricultural Incentives*, T. W. Schultz, ed. Bloomington: Indiana University Press, 1978.

Srinivasan, C.S. "The International Trends in Plant Variety Protection." *e-Journal of Development Economics* 2(2)(2005): 182-220.

Sunding, D. and D. Zilberman. "The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector." Chapter 4 in Gardner and G. C. Rausser, eds. *Handbook of Agricultural Economics*. Vol. 1a, B. L. Amsterdam: Elsevier, 2001.

U.S. Census Bureau. *U.S. and World Population Clocks.* Retrieved June 6, 2008, from http://www.census.gov/main/www/popclock.html, 2007.

Wiesmann, D., A.K. Sost, I. Schöninger, H. Dalzell, L. Kiess, T. Arnold and S. Collins. *The Challenge of Hunger 2007*. Bonn: Deutsche Welthungerhilfe, International Food Policy Research Institute, Concern Worldwide, 2007.

World Bank. *World Development Indicators Online*. Retrieved June 5, 2008, from http://www.worldbank.org/data, 2007.

Wright, B.D., P.G. Pardey, C. Nottenburg, and B. Koo. "Agricultural Innovation: Economic Incentives and Institutions." Chapter in R.E. Evenson and P. Pingali, eds. *Handbook of Agricultural Economics: Volume 3* Amsterdam: Elsevier, 2007.

Wright, B.D. and P.G. Pardey. "The Evolving Rights to Intellectual Property Protection in the Agricultural Biosciences." *International Journal for Technology and Globalization* 2 (1/2)(2006): 12-29.

Wright, B.D. 1983. "The Economics of Invention Incentives: Patents, Prizes, and Research Contracts." *American Economic Review* 73(4): 691–707.

Table 1: Size distribution of agricultural research agencies in sub-Saharan Africa, 2000

Number of fte researchers[a]	Government		Higher education	Nonprofit	Private	Total
	Principal	Other				
			(number of agencies)			
Less than 5	7	34	103	7	24	175
5 – 9	7	27	42	4	5	85
10 – 19	15	14	32	5	–	66
20 – 49	29	16	23	3	–	71
50 – 99	11	3	–	1	–	15
100 – 200	10	–	–	–	–	10
Greater than 200	5	–	–	–	–	5
Total	84	94	200	20	29	427

Source: Beintema and Stads (2004).

[a] fte is full-time equivalents.

Table 2: Agricultural research expenditures by region, 1981 and 2000

					Shares			
			Private	Total	Public		Private	Total
		2000	2000	2000	1981	2000	2000	2000
	(million 2000 international dollars)				*(percentage)*			
Asia & Pacific (18)	2,236	5,089	499	5,588	15.7	25.1	3.7	16.6
China	587	1,763	--	--	4.1	8.7	--	--
India	332	1,160	--	--	2.3	5.7	--	--
Latin America & Caribbean (27)	1,821	2,341	116	2,457	12.8	11.5	0.9	7.3
Brazil	628	929	--		4.4	4.6	--	--
Sub-Saharan Africa (44)	1,054	1,194	21	1,214	7.4	5.9	0.2	3.6
South Africa	200	243	--	--	1.4	1.2	--	--
West Africa and North Africa (18)	792	1,407	51	1,458	5.6	6.9	0.4	4.3
Subtotal, Developing Countries (107)	5,903	10,031	687	10,717	41.4	49.4	5.1	31.8
High-Income Countries (22)	8,340	10,268	12,682	22,950	58.6	50.6	94.9	68.2
Japan	1,821	1,646	--	--	12.8	8.1	--	--
U.S.	2,569	3,882	--	--	18.0	19.1	--	--
Total (129)	14,243	20,298	13,369	33,667	100.0	100.0	100.0	100.0

1981 Public Expenditures

Source: Authors' calculations based on ASTI (Agricultural Science and Technology Indicators) data reported in Pardey et al. (2006). Currency units formed using revised purchasing power parity indexes from the World Bank obtained from Martin (2008). See text footnote 7 for additional details.

Notes: These estimates exclude East Europe and former Soviet Union countries. To form these regional totals we scaled up national spending estimates for countries that represented 79 percent of the reported sub-Saharan African total, 89 percent of the Asia and Pacific total, 86 percent of the Latin America and Caribbean total, 57 percent of the West Asia and North Africa total, and 84 percent of the high-income total.

Table 3: Concentration of public expenditures in agricultural research and development, 1981 and 2000

Countries Included	Share of Total Public Ag R&D Spending		Share of 2000[a]*	
	1981	2000	Ag GDP	Population
Top 5%	46.9	49.9	45.6	53.4
Top 10%	66.1	64.9	51.4	58.0
Top 20%	83.0	81.8	68.6	71.4
Bottom 80%	17.0	18.2	31.4	28.6
Bottom 50%	3.2	3.3	13.0	7.1

Source: Authors' calculations based on ASTI data reported in Pardey et al. (2006).

a. Entries reflect the shares of agricultural GDP and population for the countries selected based on criteria for public agricultural R&D spending. For instance, the top line reflects the shares of agricultural GDP and population in the top 5 percent of countries ranked by their public agricultural R&D spending.

Table 4: Intensities of public agricultural research, 1981, 1991, and 2000

	Public Agricultural R&D Spending								
	Per Unit of Agricultural GDP			Per Capita			Per Capita of Economically Active Agricultural Population		
	1981	1991	2000	1981	1991	2000	1981	1991	2000
Asia & Pacific (18)	0.41	0.40	0.44	0.96	1.19	1.59	2.82	3.59	5.12
China	0.41	0.35	0.40	0.58	0.82	1.37	1.42	1.95	3.45
India	0.18	0.24	0.34	0.47	0.73	1.14	1.58	2.69	4.40
Latin America & Caribbean (27)	0.46	0.49	0.53	5.22	4.67	4.73	43.30	47.77	57.35
Brazil	0.91	1.51	1.43	5.05	6.02	5.41	36.05	60.40	70.31
Sub-Saharan Africa (44)	0.84	0.77	0.68	3.05	2.53	1.86	9.77	8.81	6.72
South Africa	1.48	2.15	3.04	6.70	5.54	5.53	107.04	108.66	139.78
West Africa and North Africa (18)	0.62	0.54	0.63	3.36	3.76	3.73	19.85	28.31	30.78
Subtotal, Developing Countries (107)	0.49	0.48	0.50	1.81	1.92	2.13	5.99	6.70	7.98
High-Income Countries (22)	1.62	2.33	2.36	10.97	13.11	12.01	318.33	531.20	696.87
Japan	2.64	3.20	3.62	15.47	17.48	12.96	296.49	488.08	594.30
United States.	1.68	2.64	2.65	10.99	12.62	13.62	662.89	911.74	1,283.79
Total (129)	0.84	0.90	0.84	3.55	3.80	3.65	14.12	15.74	15.95

Source: Authors' calculations based on ASTI data reported in Pardey et al. (2006).

Note: See Table 2.

Table 5: Agriculture and agricultural R&D in the United States, India, and Sub-Saharan Africa, 2000

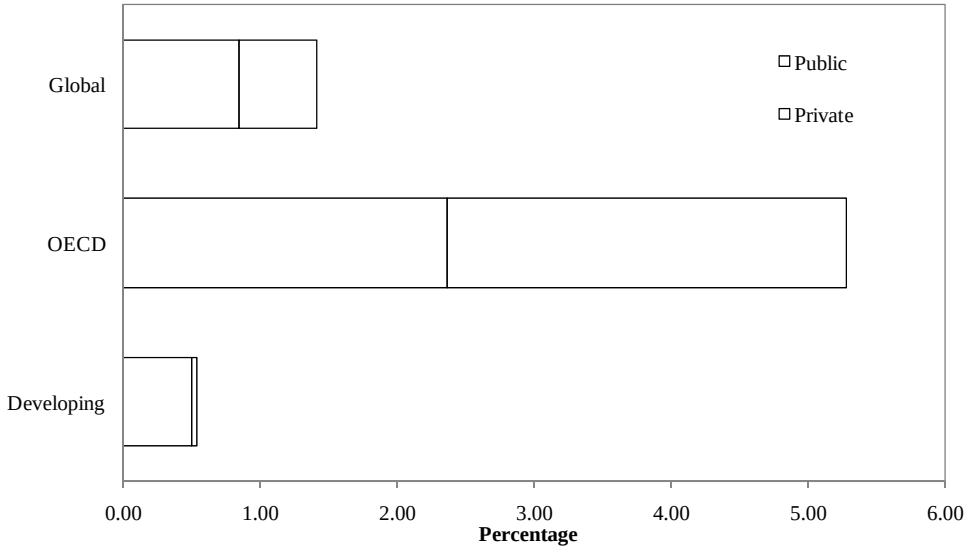
	United States.	India	Sub-Saharan Africa
Agricultural (arable) area (mill ha)	175.5	169.7	181.5
Ag land/labor ratios (arable ha per worker)	58.88	0.64	1.04
Land + Labor cost shares (percent)	45%	74%	80%
Number of Public Agencies	51	122	390
Total Public FTEs	9,368	8,100	12,224
FTEs with PhDs	100%	63%	25%
Agencies < 20 fte	4%	26%	76%
Agencies > 100 fte	96%	33%	3.5%
Total Public Expenditures[a] (million)	$3,882	$1,160	$1,194
University share of public	78%	45%	19.3%
Total Private Expenditures (million) [a]	$4,666	$129	$21
Private share	54.6%	10.0%[b]	1.7%
Spending per FTE[a]	$414,408	$143,149	$97,642
Agricultural Research Intensity			
Public only	2.65%	0.34%	0.68%
Public and Private	5.84%	0.38%	0.69%

Source: Compiled by authors from Beintema and Stads (2004), FAOSTAT (2008), Pardey et al. (2007), Pal and Byerlee (2006), Pal (2008) and calculations based on ASTI data reported in Pardey et al. (2006).

a. All monetary figures are in 2000 international dollars.

b. Estimates based on data presented in Pardey et al. (2006). Pal and Byerlee (2006, p. 175) estimated that 11 percent of total agricultural R&D funding in India was from the private sector.

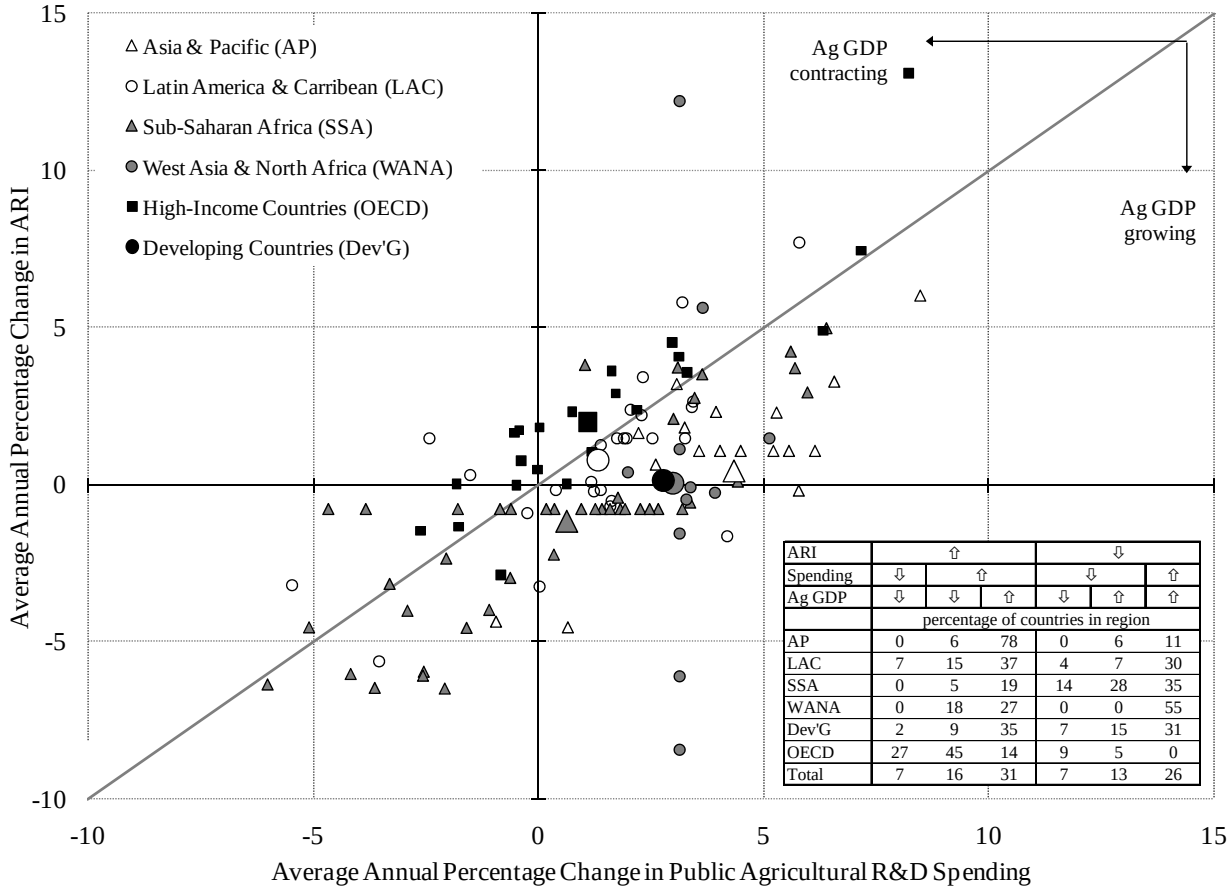
Figure 1: Public, private, and total agricultural R&D intensities, 2000



Source: Authors calculations based on Pardey, Beintema, Dehmer, and Wood (2006).

Notes: The intensity ratios measure total public and private agricultural R&D spending as a percent of agricultural output (agricultural GDP).

Figure 2: Average annual rates of growth in public agricultural R&D spending and intensities, 1982-2000

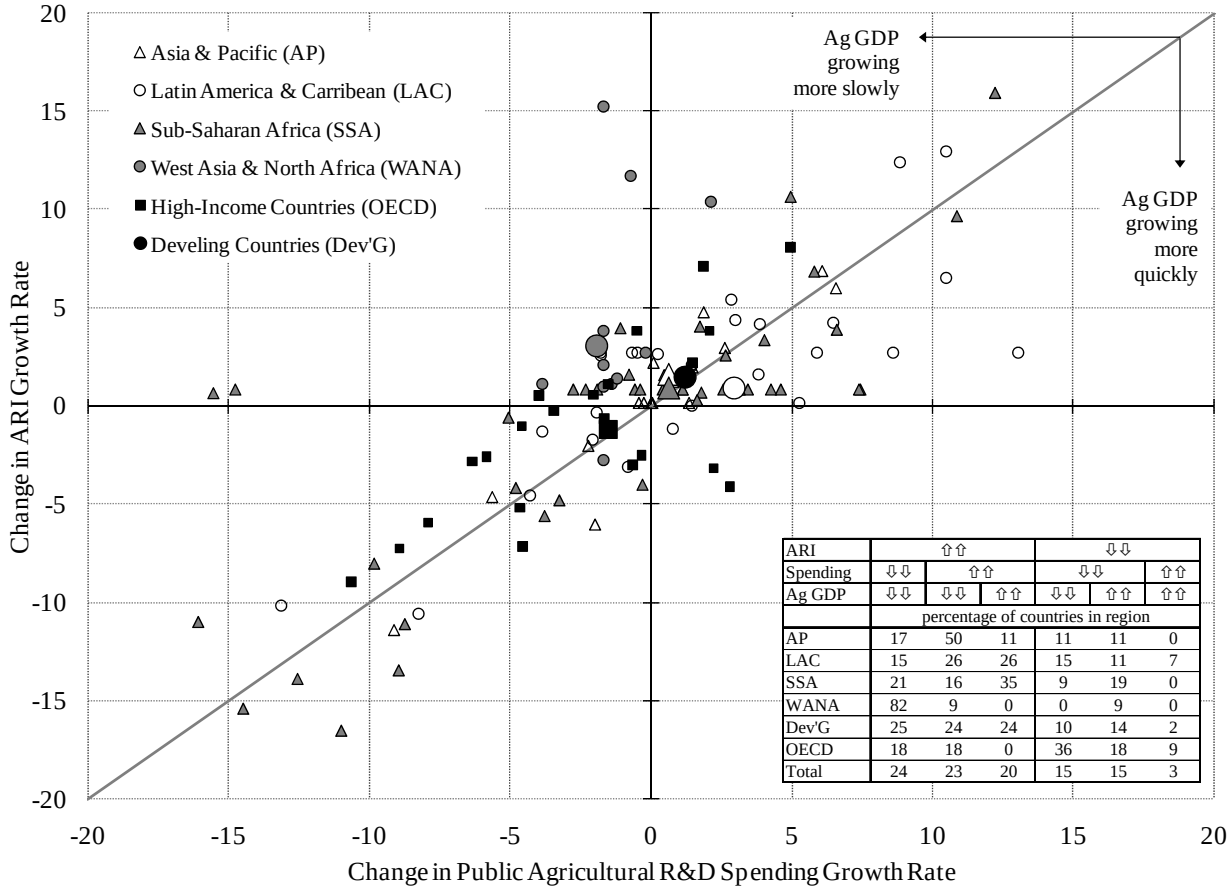


ARI	⇧			⇩		
Spending	⇩	⇧		⇩		⇧
Ag GDP	⇩	⇩	⇧	⇩	⇧	⇧
	percentage of countries in region					
AP	0	6	78	0	6	11
LAC	7	15	37	4	7	30
SSA	0	5	19	14	28	35
WANA	0	18	27	0	0	55
Dev'G	2	9	35	7	15	31
OECD	27	45	14	9	5	0
Total	7	16	31	7	13	26

Source: Authors' calculations based on data from Pardey et al. (2006). See table 2.

Notes: There is one mark for each country. A mark of the same shape and shading but larger size indicates the average growth in the aggregate spending and ARI for the region (i.e., they are essentially weighted averages of the country-specific growth rates). The table summarizes the distribution of countries in a region among sections of the scatter plot, as defined by the direction of growth in public agricultural R&D spending, public research intensity, and agricultural GDP. Year-specific growth rates were calculated as the difference between the logarithms of spending (or ARI) for the current and previous years. Data plotted are the averages of the year-specific growth rates for 1982-2000.

Figure 3: Differences between average annual rates of growth in public agricultural R&D spending and intensities, from the 1980s to the 1990s



ARI	⇧⇧			⇩⇩		
Spending	⇩⇩	⇧⇧		⇩⇩		⇧⇧
Ag GDP	⇩⇩	⇩⇩	⇧⇧	⇩⇩	⇧⇧	⇧⇧
	percentage of countries in region					
AP	17	50	11	11	11	0
LAC	15	26	26	15	11	7
SSA	21	16	35	9	19	0
WANA	82	9	0	0	9	0
Dev'G	25	24	24	10	14	2
OECD	18	18	0	36	18	9
Total	24	23	20	15	15	3

Source: Authors' calculations based on data from Pardey et al. (2006). See table 2

Notes: There is one mark for each country. Each mark shows the change in the average growth in spending and ARI between the 1980s and the 1990s. For instance, if both are positive, then both spending and ARI grew more quickly in the 1990s then they did in the 1980s. A mark of the same shape and shading but larger size indicates the change in average growth in the aggregate spending and ARI for the region (i.e., they are essentially weighted averages of the country-specific growth rates). The table summarizes the distribution of countries in a region among sections of the scatter plot, as defined by the direction of change in growth in public agricultural R&D spending, public research intensity, and agricultural GDP. Year-specific growth rates were calculated as the difference between the logarithms of spending (or ARI) for the current and previous years. Data plotted are the differences between the averages of the year-specific growth rates for 1982-1990 and 1991-2000.