SETTING MEANINGFUL INVESTMENT TARGETS IN AGRICULTURAL RESEARCH AND DEVELOPMENT: CHALLENGES, OPPORTUNITIES AND FISCAL REALITIES[1]

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

1. The rate of growth in agricultural research and development (R&D) investment has been declining globally while a large number of developing countries have experienced negative growth rates over the past decade. Stagnating investment in sub-Saharan African agricultural research is particularly worrisome. General underinvestment is evidenced by: 1) the continuing high rates of return to research demonstrated in studies at the commodity level; and 2) by macroeconomic studies showing that the relevant Millennium Development Goals (MDGs) cannot be reached without a doubling or even tripling of research investment given estimated growth-poverty-reduction elasticities, Also of concern is new evidence that a change in the composition of research away from productivity-enhancement at the farm level is statistically related to a decline in the growth of agricultural productivity in advanced economies below historical levels. This trend may be considered another form of underinvestment that reduces potential spillovers in the future. Policy makers are reminded that growth in agricultural productivity provides the consumption, savings and taxes needed for development and attainment of social goals.

2. Capacity in agricultural research is increasingly concentrated in a few leading countries in each region. While efforts are underway to create new structures or mechanisms for collaboration across the global, regional and national levels, policy makers are reminded that no country is too poor or too small to support a national effort that is "sufficient" to gain from global knowledge. Various investment targets have been adopted over the years such as CAADP's "public expenditure on agriculture equal to 10 percent of the national budget. " Seen from the results side, investment should be sufficient to produce 6 percent growth in agricultural production (or to meet MDG1). Such targets do not provide guidance on the feasibility of the target and how fast one can build up the institutional and human capacity to achieve them.

3. One of the main indicators to compare relative R&D investment levels, is the ratio of agricultural research investment over agricultural output, the so-called "agricultural research intensity ratio (ARI)". An ARI of 1 percent has been seen by many as a target that low income agriculturally-based countries should strive for. However, the ARI by itself is influenced by several factors that need to be studied in depth at the country level. The ARI can be decomposed into an identity with four components: 1) priority to research within agricultural expenditure; 2) priority to agriculture in total public expenditure; 3) fiscal capacity measured as the ratio of public expenditure to gross domestic product (GDP) and 4) the (inverse of the) share of agriculture in the GDP. Analysis of each of these elements in a country's effort highlights the importance of strategy and priorities; the institutions and incentives; public sector finance and public expenditure management; and the role of global partners.

4. Emerging challenges, such as adaptation to climate change and increasing variability of weather, water scarcity, and increased price volatility in global markets will be faced by many countries that are least able to adapt to existing stresses. This lends increasing importance to developing the human and institutional capacity in agricultural research at the national level to interact with regional and global efforts underway. A systemic approach to planning will bring universities and research institutes closer together.

SECTION 1 INTRODUCTION

This paper is ultimately aimed at policymakers who ask "Is there enough investment in agricultural research and development (R&D)?" They are constantly being reminded by declarations made, commitments signed and targets held up that assert that they must do more or better. In order to provide some analytical structure and limits to the discussion, we look at "underinvestment" separately from the demand and the supply sides and then at the investments, policy actions and institutional arrangements that are needed to bring supply and demand into balance.

This paper has four sections in addition to this introduction. Section 2 sets the scene by providing historical trends in human and financial investments in agricultural research and development (R&D). Section 3 looks at "underinvestment" in three ways (two technical and one political). First, evidence of a continuing high rate of return relative to the social rate of discount is a formal definition of "underinvestment" since additional investment would add more to social gains than to social costs. Second, failure to maintain on-farm productivity growth at its historical trend and potential contribution is a sign of underinvestment. Finally, if there are large gaps between the resources required to attain political commitments, e.g. the Millennium Development Goals (MDGs) with respect to poverty and hunger; there is underinvestment with respect to political commitments. We do not say anything at this point about how fast the gaps must be eliminated if we want to avoid waste.

Turning to the "supply side" in Section 4, we pose the question whether a country's national effort is commensurate with its financial and human resource capacities to permit it to "do more" to deliver on commitments to investment targets set in various international fora. On the finance side, we go into several public finance issues on the taxation and expenditure sides (which are not independent of each other). We create an identity out of the agricultural research intensity ratio, analyze the four components that determine its value, and comment on what might be done to increase investment in R&D. On the human resource side, we identify gaps in both research and higher education that affect the ability of research institutions to ramp up their effort in response to emerging challenges. The financial resource needs cut across the global to local scales.

Section 5 deals with new challenges imply not just reinvestment in agricultural R&D but also necessary investment in other parts of the knowledge system for balanced growth. A demand for more highly trained researchers to deal with climate change, price volatility in global markets, or water scarcity is a demand on the university system to expand MSc and PhD training. The expanded cadre provides valuable research support to existing scientists while learning the advanced skills needed to become senior researchers.

New challenges bring with them new approaches, demands for new skills and new institutional arrangements for collaborative research. The time and process by which these new arrangements come about are necessary investments.

SECTION 2: TRENDS IN AGRICULTURAL R&D INVESTMENTS[3]

2.1 Public agricultural R&D spending

Global public agricultural R&D investment (including government, nonprofit, and higher education sectors) totaled $23 billion in 2005 PPP dollars in 2000, the latest year for which comparable global data are available.[4]

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[3] This section draws on Beintema and Stads (2006, 2008a+b), Stads and Beintema (2009), and underlying datasets of the Agricultural Science and Technology Indicators (ASTI) initiative (www.asti.cgiar).

[4] Financial data in this paper are reported in real values using gross domestic product (GDP) deflators using the benchmark year 2005 and purchasing power parity (PPP) indexes taken from the World Bank (2008a). PPPs are synthetic exchange rates used to reflect the purchasing power of currencies, typically comparing prices among a broader range of goods and services than conventional exchange rates. These global trends differ from those reported in Pardey et al. (2006). These revisions were in response to World Bank adjustments to its comparative pricing of goods and services across countries (using PPP indexes), reclassification of non-OECD high-income countries, and new estimates for Latin America and a number of other countries (Beintema and Stads 2008a).

Total public investment increased considerably from the $16 billion reported in 1981 (Table 1). But this increase did not take place equally across all regions in the world. Spending in the Asia-Pacific region more than doubled during the two-decade period or, measuring in growth rates, increased at 4.2 percent per year (Figure 1).[5] This was largely a result of high growth in agricultural R&D spending in the two largest countries, China and India (annually 4.4 percent and 5.8 percent, respectively). In contrast, spending in sub-Saharan Africa only grew, on average, by 0.6 percent per year during 1981-2000. More worrisome is that the spending for the region as a whole contracted slightly during the 1990s with more than half of the sub-Saharan African countries for which time series data were available spending less in 2000 than they did in 1991.

As a result of these different regional growth patterns, the distribution of agricultural R&D spending changed during the two decade period. Due to the high increase in total spending in the Asia-Pacific region, its share in the global total increased from 12 percent in 1981 to 20 percent in 2000. As a result the shares of sub-Saharan Africa and Latin America declined during the 20-year period to 5 percent and 12 percent of the total, respectively. Interestingly is that the total public agricultural R&D spending in sub-Saharan Africa as a whole was lower than total spending in Brazil, the largest public investor in Latin-America, and considerably lower than the spending levels in India and China. Although spending in high-income countries as a whole continued to grow in absolute terms, their share of total global spending declined from 62 percent to 57 percent. The share of spending by low and middle income countries increased from 9 percent to 11 percent and 29 percent to 32 percent, respectively.

Table 1: Total public agricultural R&D expenditures by income class and region, 1981, 1991, and 2000

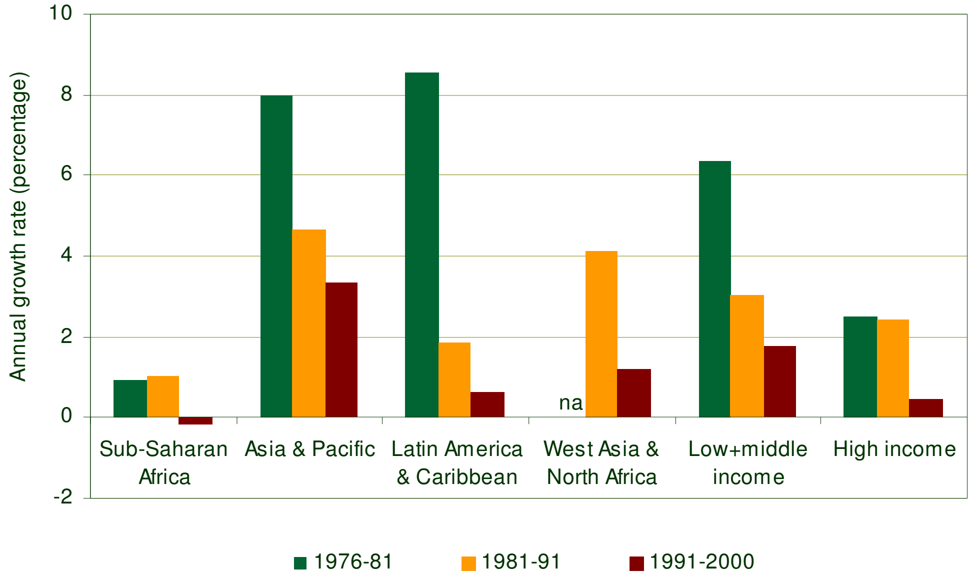
Country category	Public agricultural R&D spending			Regional share of global total		
	1981	1991	2000	1981	1991	2000
	(*million 2005 PPP dollars*)			(*percent*)		
Country grouping by income class						
Low income (46)	1,410	2,009	2,564	9	10	11
Middle income (62)	4,639	6,301	7,555	29	30	32
High income (32)	9,774	12,577	13,313	62	60	57
Total (140)	***15,823***	***20,887***	***23,432***	***100***	***100***	***100***
Low- and middle-income countries by region						
Sub-Saharan Africa (45)	1,084	1,253	1,239	7	6	5
China	713	1,178	1,891	5	6	8
India	400	748	1,301	3	4	6
Asia–Pacific (26)	1,971	3,287	4,758	12	16	20
Brazil	1,005	1,433	1,209	6	7	5
Latin America and the Caribbean (25)	2,274	2,697	2,710	14	13	12
West Asia and North Africa (12)	720	1,074	1,412	5	5	6
Subtotal (108)	***6,049***	***8,310***	***10,119***	***38***	***40***	***43***

Sources: Beintema and Stads (2008a) based on ASTI datasets (www.asti.cgiar.org) and other secondary sources.

Notes: The number of countries included in the regional totals is shown in parentheses. These estimates exclude Eastern Europe and former Soviet Union countries. Estimation procedures and methodology are described in Pardey et al. (2006) and various ASTI regional reports available at www.asti.cgiar.org.

[5] The regional totals refer to developing countries (defined as low and middle income countries) only and exclude high income countries such as South Korea in the Asia-Pacific region and Israel and Kuwait in the Middle East and North Africa region.

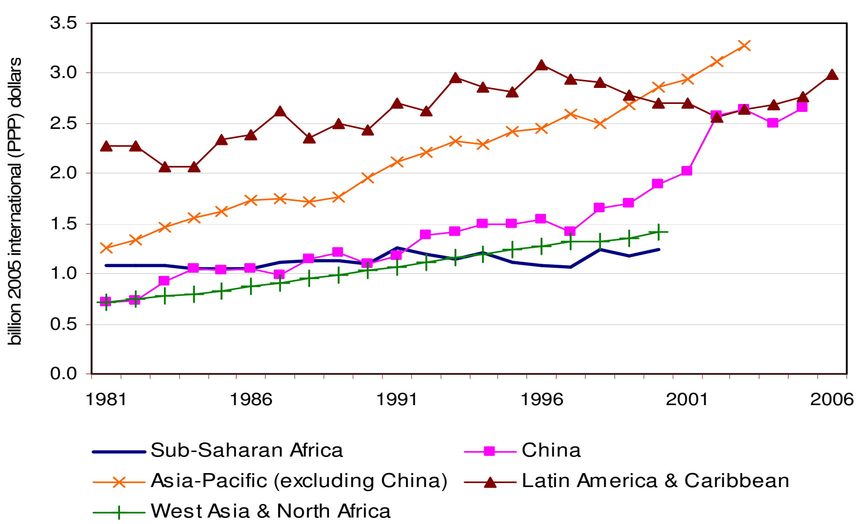
Figure 1: Annual growth rates in agricultural R&D spending, 1976-2000



Sources and Notes: See Table 1.

Although data on global public agricultural R&D investments patters since 2000 are still unavailable,[6] more recent data collected by the Agricultural Science and Technology Indicators (ASTI) initiative show that investments continued to grow in China and India (Figure 2). Agricultural R&D expenditures in Latin America and the Caribbean rebounded in recent years following a period of contraction during the late-1990s, which was mostly due to financial crisis in a number of Southern Cone countries. No recent investment data are yet available for sub-Saharan Africa, but new information collected by the ASTI initiative in 14 countries indicate that the overall research capacity, in terms of the number of full-time equivalent (FTE) researchers has increased for many countries since 2000 (Beintema and Di Marcantonio 2009). Although this is useful information, it cannot be used as proxy for the direction of investment trends within the region.

Figure 2—Public agricultural R&D investment trends in developing countries, 1981-2006



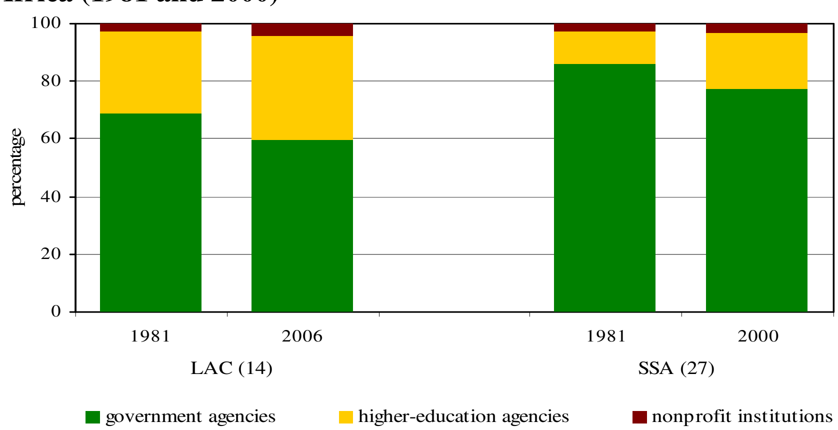
Sources: ASTI datasets and secondary sources underlying Beintema and Stads (2008a+b) and Stads and Beintema (2009).

[6] Data collection efforts by the ASTI initiative are underway in sub-Saharan Africa and will be expanded to a number of other low- and middle-income countries to ensure a new global update for the year 2009.

Public agricultural R&D, however, has become increasingly concentrated in just a handful of countries (Pardey et al. 2006). The top five countries in terms of agricultural R&D spending, the United States, Japan, China, India, and Brazil, spent 48 percent of total global public agricultural R&D; from 41 percent in 1991. Meanwhile, only 6 percent of the agricultural R&D investments worldwide were conducted in 80 (mostly low-income) countries that combined had a total of more than 600 million people and accounted for 14 percent of the world's agricultural land area. In Latin America about three-quarters of the total public investments in agricultural R&D were spent by only three countries, Brazil, Mexico, and Argentina. Since the mid-1990s the investment gap has widened between the region's low and middle income countries, which in part was the result of sharp cuts in research expenditures in some of the poorer, more agriculture-dependent countries such as Guatemala and El Salvador. Similarly in Asia, although less pronounced, a knowledge divide between the region's rich and poor countries and the scientific "haves" and "have-nots" is becoming more and more visible. During the period 1981–2002, especially in the latter decade of the period, both China and India intensified their agricultural research spending while other smaller countries, such as Malaysia and Vietnam, also realized impressive agricultural R&D spending growth. But other countries such as Pakistan, Indonesia, and Laos, proved sluggish and at times negative, largely due to the Asian financial crisis, the completion of large donor-financed projects, or high rates of inflation. In Africa agricultural research has been historically better funded in some countries such as Kenya and South Africa compared to a large number of the very poorest countries in the region, specifically in Western Africa. But there is no evidence that this divide has increased over the past few decades; this in part because of the donor dependency of many countries as well as the erratic nature of government and donor support to agricultural research over the years.

The government sector is still the main player in public agricultural R&D, in terms of execution as well as funding. The government sector accounted for 60 percent and 77 percent of total FTE staff in Latin America (data for the year 2006) and Sub-Saharan Africa (data for the year 2000/1), respectively (Figure 3). Despite this leading role of the government sector, the higher-education sector has gained prominence and quite a number of countries. It accounted for 36 percent of total public agricultural R&D in Latin America compared to 29 percent in 1981. The higher-education shares in sub-Saharan Africa increased from 11 percent in 1981 to 19 percent in 2000. In absolute terms, the total number of FTE researchers employed in the higher education sector almost doubled in Latin America and tripled in Sub-Saharan Africa. In a number of countries (e.g., Argentina and Mexico), the research capacity in higher education approaches that found in the government sector. In India the higher education sector has surpasses the government sector in terms of FTE agricultural research staff. The latter is the result of the integration of research, extension, and education in the India system. Despite the increasing share of the higher-education sector as a whole, the individual capacity of each faculty/school remains often very small and the agricultural higher-education system fragmented (e.g., Sudan, Philippines, and Nigeria).

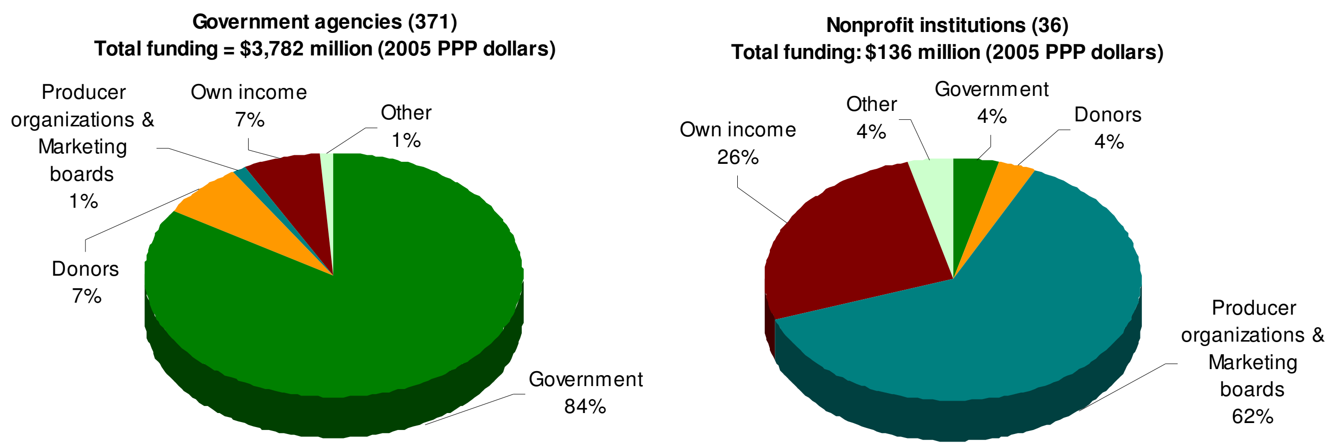
Figure 3: The institutional orientation of agricultural research in LAC (1981 and 2006) and sub-Saharan Africa (1981 and 2000)



Source: ASTI datasets underlying Beintema and Stads (2004) and Stads and Beintema (2009).
Note: Shares are measured in terms of full-time equivalent (FTE) researchers. The number of countries is indicated in parenthesis

The government sector is also still the largest contributor to public agricultural research (Figure 4). Government allocations accounted for an average of 81 percent of total funding received by a sample of more than 400 government agencies and nonprofit institutions in 53 developing countries. Only 7 percent of total funding was received from donor contributions, in the form of loans or grants. This share was mostly driven by the high donor dependency of government agencies in sub-Saharan Africa. For the main government agencies in 23 countries for which data were available, 35 percent of their funding came from donor loans and grants in 2000/1. Funding generated through internally generated funds, including contractual arrangements with private and public enterprises, accounted for an average of 7 percent of total funding. The 36 nonprofit organizations in the sample received close to two-thirds of their funding contributions from producer organizations and marketing boards. These contributions were mostly collected through taxes raised on export or production of commercial crops. The nonprofit organizations were also more active than the government agencies to raise income from internally generated resources, which included contract with private and public enterprises (26 percent).

Figure 4—Composition of funding sources for various years since 2000



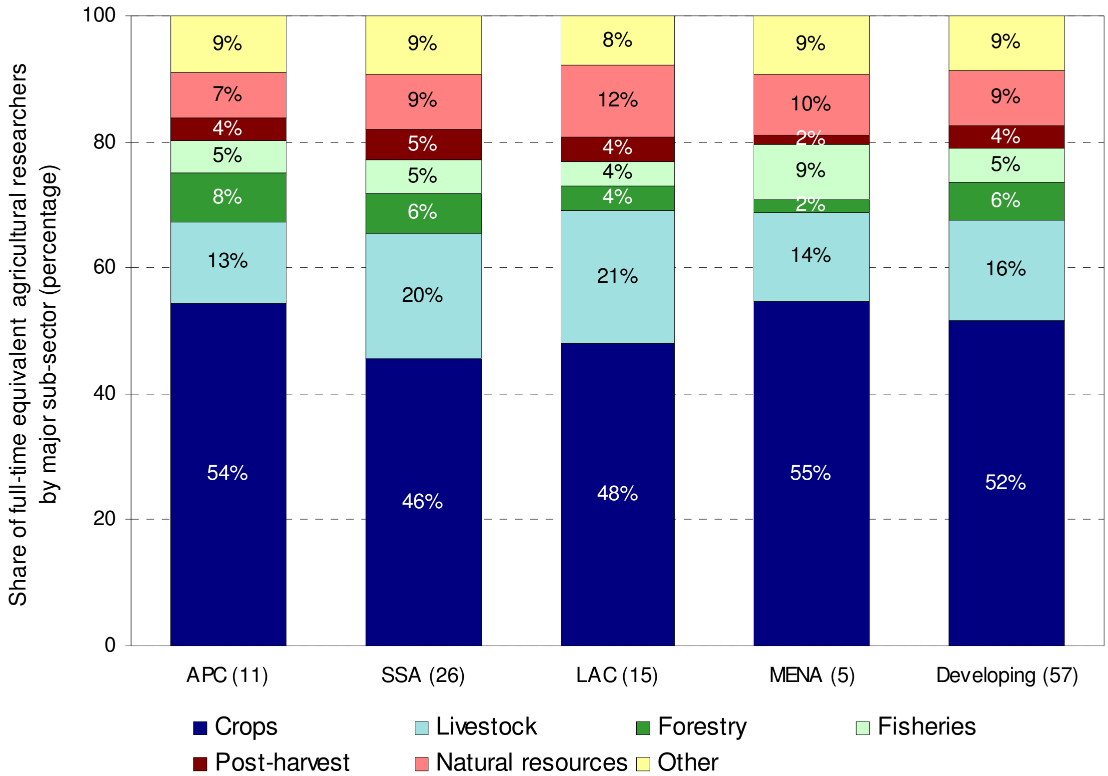
Source: ASTI datasets underlying Echeverria and Beintema (2009).

Note: Own income includes contracts with private and public enterprises. Data is for 53 developing countries but exclude China, Nigeria, and South Africa; large countries in terms of agricultural R&D investments.

Although government allocations still present the main source of funding, there are again considerable differences across countries. A number of developing countries depend on non-governmental sources of funding. In Africa this is the result of high donor dependency. A number of countries in Africa and other regions, however, have increased the diversity of their funding sources and include considerable income from sale of products or services, contractual arrangements with public and private enterprises, or contributions from producer organizations through taxation of exports or production.

More than one half of the total FTE researchers in agricultural R&D in a sample of 58 developing countries were involved in crops research while 16 percent focused on livestock research (Figure 5). The remaining one third of the researchers focused on forestry (6 percent), fisheries (5 percent), natural resources (9 percent), postharvest (4 percent) and other agricultural disciplines. Researchers in sub-Saharan Africa and Latin America and the Caribbean spent relatively more time on livestock research compared to the overall research staff in Asia-Pacific and Middle East and North Africa regions.

Figure 5—Research orientation of research staff by main sub-sector

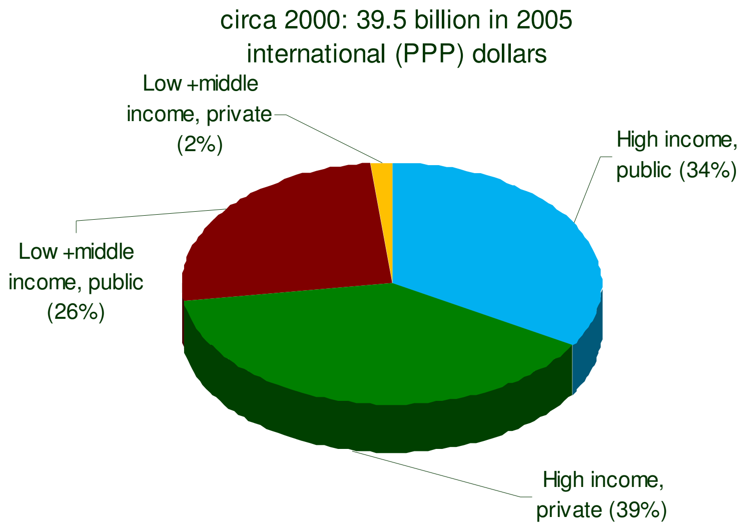


Source: Authors calculations based on ASTI datasets (www.asti.cgiar.org).
Note: The number of countries included in the regional totals is shown in parentheses. SSA stands for sub-Saharan Africa, APC for Asia-Pacific Countries (and excludes here China), LAC for Latin America and the Caribbean, and MENA for Middle East and North Africa. SSA data is for 2000/01, APC for 2002, LAC for 2006, and MENA for 2002/3.

2.2 Private agricultural R&D spending

Data on private sector investments in agricultural R&D remain very limited. In 2000, the only year for which global estimates are available, the private sector spent an estimated $16 billion 2005 PPP dollars (Figure 6); 41 percent of global total (public and private). Almost all of these private sector investments were made by private companies performing agricultural R&D in high income countries. Investments by the private sector in the developing world accounted for only 2 percent of the total public and private agricultural R&D investments in 2000; of which most was done by Asian private companies (Beintema and Stads 2008a). The private sector plays a stronger role in terms of funding agricultural research given that many private companies contract research out to government and higher education agencies. But the role of the private sector in most developing countries is and will remain small given the limited funding opportunities and incentives for private research. Furthermore, most private sector research in developing countries focuses on the provision of input technologies or technical services for agricultural production. Most of these technologies are, however produced in the high income countries (Pardey et al 2006).

Figure 6—Composition of public and private agricultural research investments



Source: ASTI datasets and secondary sources underlying Beintema and Stads (2008).

There is only limited information on the level of private sector involvement over time or on the type of research private companies are conducting. Alston et al (1999) found that only 12 percent of private research in Australia, the Netherlands, New Zealand, United Kingdom, and United States were focused on farm-oriented technologies in 1992; the corresponding share in the public sector was 80 percent for these countries. Food and other postharvest accounted for 30-90 percent in Australia, the Netherlands, and New Zealand, chemical research between 40-50 percent in the United Kingdom and United States. Pray and Fuglie (2001) found that share of private sector investments in the total agricultural R&D investments had grown during mid-1980s to mid-1990s in China, India, and Indonesia (in a sample of seven Asian countries) and was higher than the growth in public sector investments. But the growth in private sector investments was uneven across subsectors. Investments in the agricultural chemical sector and, in lesser extent, the livestock sector increased substantially while growth was slower in other subsectors such as plantation crops and machinery.

2.3 International agricultural R&D investment

The majority of international agricultural R&D is carried out by the 15 research centers of the Consultative Group on International Agricultural Research (CGIAR). The first four centers were established during the late 1950s and the 1960s, with considerable financial support from the Rockefeller and Ford Foundations. During the 1970s, the number of centers increased to 12 and the funding received per center increased over the decade. This led to a tenfold increase (in nominal terms) in the total CGIAR investments. Total funding continued to increase during the 1980s, but at a lower pace. During the 1990s, however, total funding grew less than the increase in the number of centers and spending levels per center could not be maintained. Since 2000, overall funding to the CGIAR has increased, but a larger proportion of this funding is support for specific project and programs of research involving different centers and non-CGIAR research organizations (Beintema et al. 2008; Pardey et al. 2006).

There a number of other international research providers, mostly with a regional or sub-regional focus. For example, the two largest non-CGIAR agencies conducting research in Africa are the French-headquartered International Cooperation and Agricultural Research for Development (CIRAD) and the Institute for Research and Development (IRD). In the Asia region, the Australian Centre for International Agricultural Research (ACIAR) does not conduct research in the region’s developing countries itself but develops international agricultural research partnerships. The Japanese International Research Center for Agricultural Sciences (JIRCAS) mandate covers all developing countries; most of its agricultural research is done in Asia. Two important regional agencies that conduct agricultural research in Latin America and the Caribbean are the Agronomic Center for Research and Education (CATIE) and the Caribbean Agricultural Research and Development Institute (CARDI). A number of other international agencies are also active in agricultural R&D in these three regions (Beintema and Stads, 2006, 2008; Stads and Beintema 2009).

SECTION 3: THERE IS "UNDERINVESTMENT" IN AGRICULTURAL R&D: THREE DEFINITIONS

We argued in the introduction that "underinvestment" in research could be asserted where 1) the rate of return on research was consistently higher than the social rate of return on alternative investments; 2) where the nature of investment had changed so that the country was failing to maintain historical growth in on-farm productivity, and 3) gaps between current investments and the resources really needed to attain pre-set goals.

3.1 Evidence from rates of return analysis

The "underinvestment hypothesis" is a straightforward application of marginalist economic theory: if by policy decision or a budget constraint the social value of the last unit of product consumed (or input employed) is greater than the social cost, then there is underconsumption or underuse of the factor because it would pay to borrow until the social gain and social cost are equal. If projects are ranked in descending order by their expected rates of return (call it the marginal efficiency of investment) and the return of the last project undertaken is higher than the social (opportunity cost of capital), this is prima facie evidence of underinvestment.

Hundreds of individual studies of the social rate of return to research consistently show that the rate of return to public investment in agricultural research (40-50 percent) is higher than either the social rate of return on capital or other opportunities for public investment. In general the return to public investment is higher than the private rate of return even after allowing for the marginal excess tax burden of the tax collection system and the returns accrued to farmers. This because it is impossible to appropriate many of the benefits associated to the research done by private firms (Widmer et al 1988; Evenson and Westphal 1995). There is no tendency for the rate of return to decline over time. Furthermore, it appeared that the rates of return may be higher when the research is conducted in more-developed countries (Alston et al 2000).

Roseboom (2002) defines the "underinvestment gap" as the difference between the economic rate of return of the marginal R&D project and the social rate of return. Based on the distribution of projects studied, he concluded that:

> "Under the assumption of full information and rationality, developed countries could have invested about 40 percent more in public agricultural R&D and developing countries about 137 percent more. In terms of agricultural R&D intensity, (i.e. expenditures as a percentage of agricultural GDP developed countries could have invested 2.8 rather than 2.0 percent and developing countries 1.0 percent rather than 0.4 percent in the period 1980-85."

Fuglie and Heisey (2007) analyzed the economic returns of public agricultural R&D in the Unites States and summarized their findings as follows:

- "There appear to be significant social returns to private agricultural research. The private sector is able to capture only a share of the productivity benefits from its technology.
- Agricultural research generates long-term benefits. Public research undertaken today will begin to noticeably influence agricultural research productivity in as little as 2 years and that its impact could be felt for as long as 30 years.
- Agricultural knowledge or research "spillovers" across state and national boundaries are significant."

It is important to note that the rate of return concept measures economic benefits of agricultural investments, but do not measure non-economic impacts such as environmental, social, health, and cultural benefits and costs. These are also important when investment decisions are made, but are not included as they are different to quantify and validate (Beintema et al. 2008). Furthermore, spillovers of agricultural technologies among countries and regions account for a large share of the total social benefits of public agricultural research. When spill-ins occur, rate of returns studies will overestimate the total benefits of the research investment. Similarly, rate of return studies will underestimate the benefits when if spillovers from one country to the other are important (Alston 2002; Beintema et al. 2008). Pardey at al (2006) states that the supply and demand for spillover technologies are changing. Agricultural research in high income countries is increasingly focusing on areas away from the types of technologies that are relevant for the agricultural sector in developing countries (especially the poorest ones). Furthermore, technologies have become less mobile because of stricter intellectual property rights and other regulatory policies.

3.2 Failure to maintain historical levels of productivity growth.

It is sometimes necessary to reiterate the importance of productivity. Nobel Prize winner, Sir W. Arthur Lewis (1966) stated unequivocally that "an increase in agricultural productivity is fundamental to the solution of the problem of distribution since it makes possible simultaneous increases in mass consumption, saving and taxation." While agricultural research has proven itself good at increasing on-farm productivity (along with providing spillovers to other social goals); it is a blunt instrument for addressing those other goals directly. Other authors have underlined the importance of productivity growth. Cereal output in developing countries has grown 2.8 percent annually for three decades and yields, not area, were responsible for growth. Total factor productivity has grown along with yields. (Pingali 2009). Today's investment drives tomorrow's growth of productivity (Fuglie and Heisey 2007). Recent studies point out that historical underinvestment in research that is productivity-enhancing at the farm level explains a significant decline in the rate of agricultural productivity growth in developed countries. The greater share of agricultural innovations can be traced to organized, scientific and industrial R&D efforts funded by government and the private sector but this investment has not only slowed down but it has changed it is focused.

Pardey (2009) notes slower productivity growth in the United States in the period 1990-2005 versus growth 1961-89, and suggests several possible causes: bad weather, changing regulatory environment, degradation of natural resource base, slower growth of investment, changing composition of "agricultural research", changing private sector roles and reduced spillovers from other countries and the CGIAR. He argues that this decrease in productivity growth is partly the results of the slowdown in spending and the redirection of agricultural R&D away from maintaining or enhancing productivity.

Alston, Pardey and James (2009) point out that public investments in California agriculture have shown benefit-cost ratios of 10-to-1 indicating substantial underinvestment in agricultural research according to our first definition. In addition to a slowing and increased variability of funding, they add that recent trends indicate that the extent of underinvestment in productivity-enhancing agricultural science may be worsening:

> "Public-sector research has drifted away from on-farm productivity enhancements toward investments emphasizing food safety and quality, human health and nutrition, and natural resources and the environment. Much of this research could have social payoffs comparable to those from farm-productivity enhancing research; but a slower rate of growth in total spending and the drift of research emphasis will result in slower rates of farm productivity growth and a decline in global competitiveness."

For the developing countries, the decline in productivity-enhancing research in developed countries means that the spillover benefits to them will be reduced, just as climate change and economic conditions become worse. Alston et al note that the situation will be even worse for developing countries given a long lag structure before spillover benefits will occur.

We identify a "productivity growth failure" which is the difference between the historical rate of growth of on-farm productivity (approximately 2 percent) and the current rate of approximately 1 percent. We characterize this situation as "underinvestment" as long as the level and composition of investment keeps on-farm productivity growth below its historical trend and presumed potential.

3.3 Incremental investment needed to achieve goals to which one is committed.

There are many prescriptive targets for investment in agricultural R&D. While they all perform a useful function in saying that "we can or we should do more" the way they came to be so popular and what they mean is often forgotten. Table 3 summarizes some of the most common "targets" and the investment needs to achieve them.

For countries with adequate policies and institutions, what additional aid does it cost to reduce income poverty to the desired level? What does this imply in terms of research and other support to the agricultural sector? For countries without adequate policies, what studies and activities are needed to improve policies and institutions? If the focus is uniquely on MDG1, one would have to estimate the additional costs of attaining the health, education and environmental goals that do not come as spillovers from meeting MDG 1.

Table 3: Common prescriptive targets

Target	Argues	Qualifications	Formulation*
Agricultural Research Intensity Ratio	There is some "norm" for reinvestment in the agricultural sector related to size of the agricultural sector	Its components are more instructive than its level; There are different "norms" for different classes of country	AgRE/AgGDP Target ranges from 0.2 to 2.5
Maputo Declaration: Commitment to Agriculture	Public Expenditure in Agriculture needs to double to achieve MDG 1.	Determinants of investment needs and growth possibilities are country specific	AE/BUD = 10%
Fiscal "Effort"	Even low income country can raise government share in economy to 20%	Fiscal "will" or Fiscal "drag" is country specific	BUD/GDP $\approx$ 20%
Growth Rates to Achieve MDG 1	Overall growth must be accelerated to achieve reduction in poverty and hunger	Need to identify and prioritize sectors that can produce this growth or economy	ΔGDP/GDP = 6%
e.g. ASARECA (Omamo et al. 2006)	GDP growth of 6% produces 3% GDP per capita growth (except DRC starting from negative growth)	Implies threefold increase in agricultural sectoral and sub-sectoral growth rates. Differential growth may lead to concentration geographically	ΔAgGDP/AgGDP $\approx$ Ranges from 4.3% to 6.6%
Climate Change Adaptation (e.g. Oxfam, World Bank)	Urgent Adaptation and Mitigation ; Net addition to current aid	"Research" includes more robust estimates of economics of adaptation, study of best practices, and an intensive action learning phase.	US$10-40 billion (WB) US$50 billion (Oxfam International 2007) Annual Requirement

Note: Where AgRE = Agricultural Research Expenditure; AgGDP= Agricultural Gross Domestic Product; BUD = Government Budget (Public Expenditure); and AE = Public Expenditure on Agriculture. Δ= is the change in the variable since the last period.

* The formulations will be discussed in the next section.

Another example is the Comprehensive Africa Agriculture Development Programme (CAADP) of the New Economic Partnership of Agricultural Development (NEPAD). CAADP's strategy reinstates MDG1 to reduce poverty and hunger by one half by 2015 and postulates that it would require the economy to grow at 6 percent per annum. As one of the largest sectors, agriculture must strive for a growth rate approaching this level (with possibilities of growth widely different regionally and by commodity sub-sector). As a level of commitment by policy makers, the Maputo Declaration called upon governments to raise their expenditures on agriculture to 10 percent of GDP. The simplicity of the target "raise the rate of growth of GDP to 6 percent" belies the complexity of the task of getting there and raising expenditure on agriculture to 10 percent of national budgets may be necessary but is not sufficient. The critical question is: if the necessary changes in policies and institutions are forthcoming, how much additional financial resources will be needed to achieve the 2015 goals.

CAADP calls for increasing investment in four identified pillars as follows:

1. Extend area under sustainable land management and reliable water control (US$37 billion)
2. Rural infrastructure and trade-related capacity for market access (US$37 billion)
3. Increase food supply through a) policy, technology and farm services (US$7.5 billion), and b) disaster and emergency relief and safety nets (US$42 billion)
4. Agricultural Research, Technology Dissemination and Adoption (US$4.6 billion).

Africa would commit itself to:

- Progressively increase its domestic contribution from 35 percent to 55 percent by 2015
- Increase the private sector contribution
- Double the current annual spending on agricultural research within 10 years. (Beintema and Stads (2006) calculated that this means an increase by an average of 10 percent per year; substantially higher than the average annual growth rate of 1 percent that occurred during the 1990s.)
- Invest 10 percent of government budgets in agriculture.

A third example is the strategic priorities study done by the Association for Strengthening Agriculture in Eastern and Central Africa (ASARECA); a sub-regional organization regrouping 10 countries of the region. It carried out an analysis of the possibility of creating a regional strategy for the ten member countries that would meet the MDG with respect to hunger (Omamo et al. 2006).[7]

The study concluded that under the default "business as usual" scenario, none of the 10 ASARECA countries will achieve the 6 percent growth in GDP that is needed to achieve MDG1. It was estimated that most countries will produce less than 3 percent growth in agriculture (based on historical trends and allowing for rapid growth in some countries recovering from civil war). Other development goals, such as food and nutrition security, will remain out of reach. Meeting the goals would demand a trebling of growth rates from the current situation. Not all commodities and all regions have the potential to contribute equally.

The ASARECA study had the beneficial effect of focusing attention on the supply side and highlighted the information gaps. In the absence of field data on the various agro-ecological zones (or the time to generate it), IFPRI used crop models that predicted the expected performance of different commodities in according to soils, topography and rainfall. Looking at the drivers of demand in the region, its multi-market model helped demonstrate that regional staples, livestock products, fruit and vegetables would have the greatest impact on poverty reduction. Milk and cassava were seen as having the largest GDP growth but this would concentrate growth in a small number of countries. The study underlined that agricultural productivity growth alone would be insufficient to meet poverty reduction targets; the region would require growth in non-agricultural sectors and improvement in market conditions. This follows naturally from their identification of the areas for strategic investment as those which are of high potential, low population density and low market access, i.e. areas that require significant investment in infrastructure, markets, adaptive research and scaling up of technology.

SECTION 4: REALISTIC TARGETS SEEN FROM THE "SUPPLY SIDE": ANALYZING THE AGRICULTURAL RESEARCH INTENSITY RATIO

Placing a country's agricultural R&D efforts in an internationally comparable context requires measures other than absolute levels of expenditures. The most common research intensity indicator is the Agricultural Research

[7] A "development domain" is a homogeneous area characterized by its production potential, access to markets and population density. Investment requirements will be different among the development domains.

Intensity Ratio (ARI). It the ratio formed by the sum of agricultural R&D investments (AgRE) over the agricultural gross domestic product (AgGDP). For two decades the ARI was held up as an instrument of coercive comparison: if a country's neighbor with similar characteristics had a higher ARI, the presumption was that the country was not trying hard enough to support agricultural research.

The ARI first appeared in a World Bank sector paper on Agricultural Research in 1981[8] The authors were looking for a target figure that would establish a "norm" to which national agricultural research systems could aspire. Without an empirical basis from the developing world, they borrowed the estimated investment in science and technology investments in developed countries (around 2 percent) and this became the target figure. But this target proved to be unrealistic for low income developing countries largely due to competing claims on a low fiscal capacity and the large weight of the agricultural sector in the economy. Moreover, this target did not account for the more limited opportunities for innovation in developing countries (Roseboom 2004). Finally, the expectation that agricultural R&D investments would continue to grow at the high rates of the 1980s was not met. A more realistic research intensity target of 1 percent has been recommended[9] in more recent literature (for example, Pardey and Alston 1995; Roseboom 2004; Casas, Solh, and Hafez 1999).

4.1 Trends in the Agricultural Research Intensity Ratio (AgRE/AgGDP)

The average ARI for developing countries fluctuated slightly around 0.56 percent during 1981–2000 (Figure 7). This is often attributed to the fact that the denominator, agricultural output grew at the same pace as total public agricultural research spending, In contrast, the average ARI for the high-income countries as a group increased considerably during this two-decade period. In 2000, high-income countries spent a combined $2.35 on public agricultural R&D for every $100 of agricultural output, whereas they spent $1.51 per $100 of output in 1981. More than half of the industrialized countries for which data are available had ARIs in 2000 than in 1991. Most countries in the samples for the Asia–Pacific and Latin American and Caribbean regions also increased their intensity ratios (Beintema and Stads 2008; Stads and Beintema 2009). Only 6 of the 26 countries in Sub-Saharan Africa, however, reported higher ARIs in 2000 than in 1991 (Beintema and Stads 2006).

The use of ARIs is not always appropriate because they do not take into account the policy and institutional environment within which agricultural research occurs or the broader size and structure of a country's agricultural sector and economy. Human and capital investments have a fixed base component, regardless of the size of a country's population, especially when facilities and services are dispersed across broad areas. Furthermore, a number of countries conduct research in areas related to the agribusiness sector, whose production value is counted as manufacturing not agriculture (and hence is not included in agGDP). More importantly in this context, an increase in the research intensity could mean not a higher level of investment, but rather a decrease in agricultural output—the case for a number of high-income countries during the 1990s.

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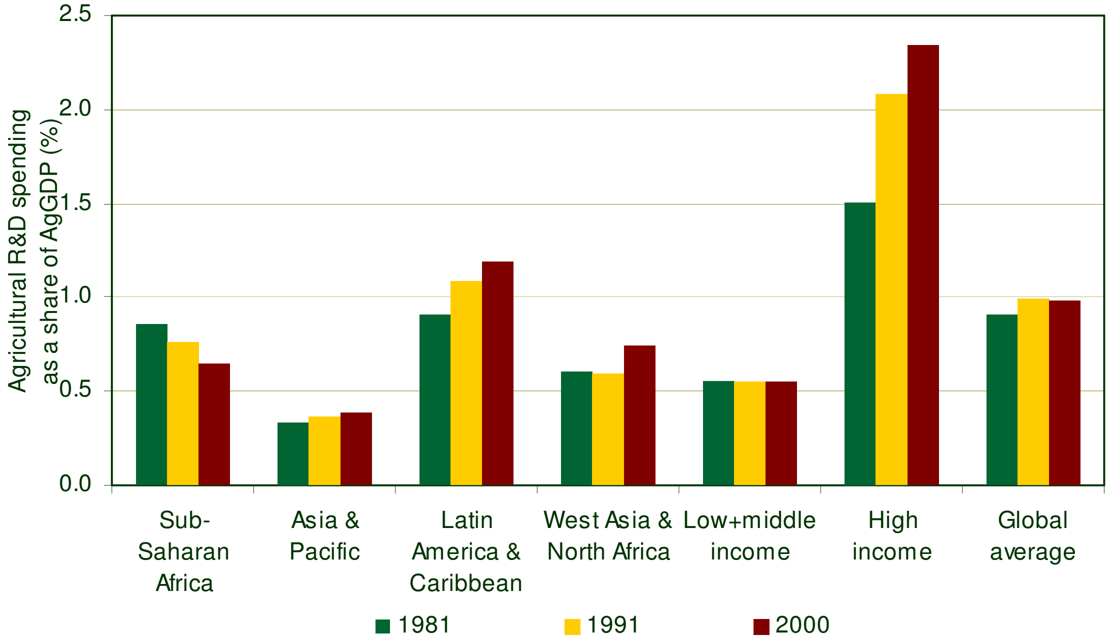
[8] For many observers, the 1980s was the "decade of the NARS" that saw the creation of new national institutes and consolidated national systems in Africa, experiments with "fundaciónes" in Latin America and second generation council models in Asia.

[9] It is "recommended" in the sense that it could be attained by even poor countries if all the priority and institutional factors were functioning as desired.

Figure 7: Intensity ratios of agricultural R&D spending, 1981, 1991, and 2000



Sources and Notes: See Table 1.

A number of countries, such as China and India, continue to have relatively low ARIs (Beintema and Stads 2008). Nevertheless, both of these countries have significantly increased their agricultural R&D investments over the past decade or so, such that their agricultural research systems are well equipped in terms of both infrastructure and human resources. Specific areas, however, may require further investment. Consequently, ARIs need to be considered within the appropriate context of investment growth, human resource capacity, and infrastructure.

While it is clear in cross-section that rich countries have higher ARIs than poor countries, it will be necessary to go into the budget detail country by country to understand what its driving this increase and its implications for the contribution of research to growth and poverty reduction. (Elliott 1995).

4.2 What do trends in the ARI tell us about research "effort"?

The ARI by itself can only be the start of a discussion: it is necessary go beyond the "reinvestment in agriculture" ratio by creating an identity that decomposes the ARI into four meaningful components as shown in Figure 8.

Figure 8: Agricultural Research Intensity Ratio: An identity

$$\mathbf{ARI} \equiv \underbrace{\frac{\mathbf{AgRE}}{\mathbf{AgE}}}_{\text{Priority to Research in Agriculture}} \times \underbrace{\frac{\mathbf{AgE}}{\mathbf{BUD}}}_{\text{Priority to Agriculture}} \times \underbrace{\frac{\mathbf{BUD}}{\mathbf{GDP}}}_{\text{Fiscal Capacity}} \times \underbrace{\frac{\mathbf{GDP}}{\mathbf{AgGDP}}}_{\text{Structure of the Economy}}$$

Source: Adapted from Elliott (1995).

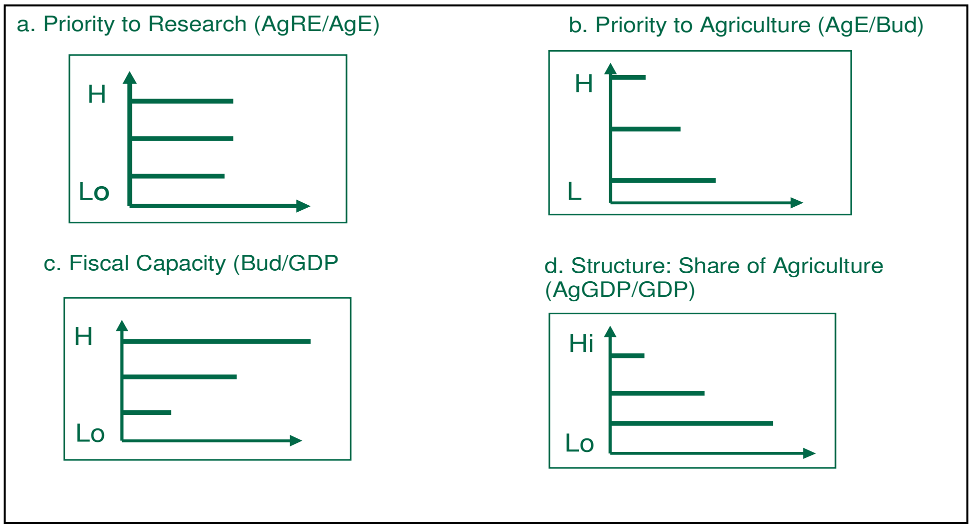
The four meaningful elements in this identity are:

1) *Priority to agricultural research:* the share of agricultural research in total agricultural expenditure (AgRE/AgE)
2) *Priority to public agricultural expenditure*: the share of public expenditure on agriculture in total public expenditure (AgE/BUD)
3) *Fiscal Effort (or Fiscal Capacity)*: the share of public revenue and expenditure in the Gross Domestic Product (BUD/GDP)
4) *Structure of the Economy*: the inverse of agriculture's share in the Gross Domestic Product (GDP/AgGDP).

Each of the elements in the identity is a ratio so the ARI ratio itself is independent of the unit of measurement for each of the elements. Each of them has its own drivers which we analyze as determinants of a country's "efforts" in agricultural research.

Figure 9 represents in schematic form each of the elements in the ARI identity arranged by income class of country (low, middle, and high) (Elliott and Pardey 1988; Elliott 1995).

Figure 9: Determinants of ARI by country income group



Note: Y Axis: level of country income per capita; X Axis: Ratios as defined

We present this schematic decomposition of the ARI components (based on the first round of collecting agricultural R&D investment data in the mid-1990s) because it highlights the structural problems low income countries have in raising their ARIs.

1. The share of expenditure on agricultural research in total agricultural expenditure is fairly similar across income levels of country (upper left quadrant). This indicates that low income countries do see the importance of research.
2. While total expenditures on agriculture are low in absolute terms in low-income agriculture-based economies, they represent a higher share of total public expenditure than in wealthier countries (upper right quadrant). The problem is simply that agriculture is also being used to finance the rest of the society.
3. The fiscal capacity (tax collections, public budgets) is a much smaller share of gross domestic product in low income countries than in higher income countries (lower left quadrant). The tax bases are more limited and focus on commodities that have easily identified points of sale.
4. The share of the agricultural sector in the economy falls with rising income (lower right quadrant). In transition and high income countries, non-agriculture can begin to support agriculture.

Recognition of the structural problems does not absolve lower income countries from striving to meet agricultural expenditure targets such as the CAADP 10 percent of budgets (ARI Component 2).

The movements in the ARI at a country level require very country-specific analysis of the drivers of each of these elements. Policy makers' commitments to invest more in agricultural R&D can be measured against the realism of their targets, the coherence of their strategy and priorities, their political and fiscal capacity and the weight of the sector they are trying to move. In the most developed countries, ARIs are rising, but this the result of lower growth rates in AgGDP compared to agricultural R&D investments and not an increase in the absolute levels of agricultural R&D investments. As with the growth of higher education expenditures with rising income, one might ask if this investment is all productive or includes some element of income-elastic consumption of research made possible by rising fiscal resources and a declining share of agriculture in the economy. Countries in the middle income group, where non-agriculture is growing, have an opportunity, if taken, to shift tax burdens away from agriculture, invest in infrastructure and other public goods and improve incentives that reinforce agricultural development. This becomes easier as the share of agriculture in the economy falls. In low-income, agriculturally-based economies, it is difficult to raise the ARI where the fiscal base is small, the size of the agricultural sector is large and the relative cost of a researcher is high.

In the following sections, we highlight some issues with "underinvestment" in research that have their origin in each of the four components of the ARI. As yet, there is no structured, cross-country information that can "unpack" each of drivers of the ARI. This has to be done at the country level at the order of policy makers who want to understand their points of intervention to improve their investment in agriculture.

4.2.1 Priority to research: the Share of Agricultural Research within all Public Agricultural Expenditure

The first determinant of the ARI is the priority to agricultural research within the overall effort to develop agriculture.

In low income economies, studies by IFPRI have suggested that agricultural research continues to be the most productive investment in support of the agricultural sector followed by education, infrastructure and input credits. "Disaggregating total agricultural expenditures into research and non-research spending reveals that research had a much larger impact on productivity than non-research spending" (Fan and Rao 2003).

Donor programs, especially in Africa, can have an important impact on allocation of resources. Programs for Highly Indebted Poor Countries (HIPC) were aimed at social goals. Public Expenditure Reviews pointed out that this affected the selection of projects within sectors, including agriculture (Bevan 2001).

The domestic political economy of budget allocations needs to be better understood. For example, in India the overall public expenditure on agriculture has remained at approximately 11 percent of the budget while the share of subsidies for fertilizer and electricity, and support prices for cereals, water and credit have steadily risen at the expense of investment in R&D, irrigation and rural roads (World Bank 2008b; Beintema Stads 2008b).

In some of the more scientifically advanced middle income countries, the higher-education sector has become a major player of agricultural research – Argentina, Costa Rica, Honduras, Mexico and Uruguay, for example, higher-education sector accounted for more than 40 percent - their government funding comes mostly from the ministries of education. In a number of other countries funding for agricultural research is allocated through the ministry of Science and Technology. In South Africa, for example, funding for the Agricultural Research Council comes through a Council of Science and Technology (with input from the National Department of Agriculture).

In North America, the changing composition of agricultural research expenditure has been a new concern: the share of research oriented to farm-level productivity-enhancement has fallen as low as 60 percent (Pardey 2009; Alston, Pardey and James 2009; Fuglie 2007).

Without contesting the value of research investment beyond the farm gate, the authors are concerned about the long term slowdown in productivity growth at the farm level for three reasons: 1) cumulative loss in productivity growth translates into a significant loss of future income; 2) there is an accompanying loss of potential spillovers to neighboring states (which may have accounted for as much as 50 percent of measured research benefits), and 3) the potential loss of new research discoveries that will be needed 10-20 years from now as both the world confronts the impact of climate change:

> "Given research lags that may be as long as 10-20 years, the effect of this slow-down in developed countries will become apparent in the future when scarcity of land and water, the impact of climate change, and population pressure will become major problems for developing countries. The stream of research outputs which have travelled fairly freely will be reduced significantly." (Alston et al 2009)

Recent studies in Canada have also documented a slowdown in productivity growth linked to declining public research investment as well as structural changes in the sector that have led to calls for more public sector research expenditure.

- Veeman et al. (2007) found that the R&D expenditure for Canadian agricultural research has shown no growth since 1990 and that the prairie crop sector TFP growth has fallen to an average of 0.51 percent per year for the 1990 to 2004 period, which is much lower than historic rates of close to 2 percent per year.
- Gray and Weseen (2008) argue that this slowdown in productivity growth highlights a need for more effective research expenditure.
- While noting that the private sector has filled the applied research gap in key crops, the Canadian Grains Council (CGC 2008) argues that the private sector has concentrated on rDNA technologies which detract from sharing and coordination. It emphasizes, therefore, the importance of public sector research in 1) sharing of discoveries, 2) developing polices that protect plant breeders, small seed producers and niche developers; and 3) facilitating greater collaboration among public and private sector research partners.

The changing composition of agricultural research expenditure is also true for some middle income countries (e.g., Argentina and Uruguay) where research into food safety, food technology and processing are budgeted to the national agricultural research institute. However, since the increase in GDP occurring further down the value chain is counted in the manufacturing sector, the rise in ARI is partly an accounting phenomenon.

4.2.2 Priority to Agriculture: The Share of Agricultural Expenditure in Total Public Expenditure (AgE/BUD)

The second component is the share of agriculture in total public expenditure. This ratio is subject to many different drivers:

- The influence of the domestic political economy. In their review of Medium Term Expenditure Frameworks, Akroyd and Smith (2007) point out the difficulties of budgeting in a "neo-patrimonial political model" and cite Palaniswamy and Birner (2006) on political challenges to increased spending on agriculture. These challenges include the low political voice of farmers, lack of knowledge of agriculture's potential for pro-poor growth, and possibly negative experiences of donors and governments with prior agricultural programs.
- The impact of donor programs. Fan and Rao (2003) pointed out that structure adjustment programs increased the size of government spending but not all sectors received equal treatment. In Africa, expenditures on agriculture, education and infrastructure all declined as a result of structural adjustment programs.

In sub-Saharan Africa, CAADP reports that seven countries have reached or exceeded the Maputo target of expenditure on agriculture of 10 percent of the budget (CAADP 2009).[10] For agriculture-based economies, the difficulty lies in the next two components: fiscal capacity (the share of tax collections and expenditures) and the sheer importance of the agricultural sector in the economy. For transforming economies, the opportunity arises to shift tax collections to growing bases in non-agriculture and to begin net reverse flows of public funds to the sector. It is in the transforming economies where fiscal policies can make or break a pro-agriculture strategy. It is with this factor in mind that we turn to the "fiscal effort" or "fiscal capacity" of a country.

4.2.3 Fiscal Effort: The share of the Government in the Economy. (BUD/GDP)

A government that can raise and spend 20 percent of GDP through tax collections can do more than a government that raises and spends only 12 percent. This includes, among other things, spending more on agriculture and agricultural research. How a country raises its revenues and how it spends its budget are

[10] The seven countries are: Mali, Madagascar, Malawi, Namibia, Niger, Chad and Ethiopia.

specialized fields in their own right. In this section, we are concerned with policy decisions that should involve some input from agricultural policy advisors.

Let us look first at the revenue side. The question of whether a country's fiscal effort and taxation of agriculture is appropriate can only be answered in the light of the specific constraints facing the country. The constraints could be the nature of taxable bases, incentive structures, the fiscal structure and the fiscal culture of the country. The following are common issues in designing fiscal policies with agricultural development in mind. :

- *Taxable bases*. Countries with agriculture as their principal resource have historically overtaxed the sector through biased macroeconomic policies and export taxes and marketing board surpluses. Oil- or mineral-rich countries with large agricultural populations have an opportunity to free agriculture from poor terms of trade and local taxation that discourage production. Failure to do so is often the cause of countries suffering from the "curse of wealth".
- *Fiscal structure*. Decentralization of fiscal responsibility to state and district levels may be a positive factor in raising revenue by bringing services and taxation together in the minds of the population. However, districts may also introduce levies on local agriculture and trade for revenue purposes that are unnecessary disincentives to development when federal grants could be substituted.
- *Fiscal culture*. Low revenue collection and low government services may result from a variety of circular problems and pathologies: low tax rates, excessive exemptions, lax tax administration, widespread non compliance and corrupt; or problems of central versus decentralized accountability. Turning the culture around may be a long term effort.
- *Fiscal returns on public investment.* Easterly (2007) argues that planners have to be aware of the fiscal effects of public investment. Benefit-cost analysis focuses on social costs and benefits but we should not be unaware of the fiscal returns and benefits of an early payback out of increased production and exports.
- *Impact of taxes on key sectors.* In the post-conflict Ugandan economy, for example, the World Bank decided that raising Uganda's fiscal effort above its low 12 percent would have been counterproductive at a time when attracting private sector re-investment in key agricultural activities was crucial for post-civil-war recovery. Future tax collections would come from expanding the base rather than raising the average rate of taxation. (Kreimer et al 2000).

The other side of the government's role is the efficiency of its expenditure. Do the projects meet all the priority criteria, does the budget process allocate funds in that direction and is this the way the funds get spent? In the remainder of this section we look at the effectiveness of public expenditure in agriculture and its link back to "underinvestment" and proposals for dealing with it.

We start with a few general observations:

- It is easier to make progress on the side of revenue reform than on the expenditure side. It only takes a handful of people to design a regulation or a tax reform but it is impossible to subject all activities to a benefit cost analysis at the project level. Such detail is necessary because it is a big mistake to lump all roads (or for that matter all agricultural projects) into one bundle and say "we do roads and agriculture" (Harberger 2009).
- Agricultural research organizations have assimilated the tools of planning and priority setting; however, they are largely absent from budget discussions where the trade-offs are made. Decision-makers rarely have the time or information to make informed choices between projects that have different fiscal and social profiles.
- Donor programs, especially in sub-Saharan Africa have had an impact on broad priorities but have not necessarily been able to control expenditures.

The World Bank introduced Medium Term Expenditure Frameworks (MTEFs) as part of the Poverty Reduction Strategy Programs (PRSPs). They were supposed to ensure that expenditures were driven by policy priorities. Various reviews have highlighted their successes and failures:

- The MTEF in Uganda as been successful in shifting expenditure composition, most notably in favor of education, as well as protecting priority sectors against cuts. It has been less successful at ensuring that budget allocations translate reliably into actual expenditures (Bevan 2001).
- The Nigeria Agriculture Public Expenditure Review pointed out seven areas of concern including discrepancies between policies and expenditures, off-budget funds, lack of information about the functional areas of public spending in agriculture, and poor data quality for planning and impact analysis (Tewodaj et.al 2008).
- They failed to link budgets with strategies and policies; spending patterns were not pro-growth or pro-poor; there was a high degree of centralization in spite of decentralization plans; there was low execution capacity; donor funding was not integrated and there was poor tracking and monitoring. (Fan 2009).

As with any budgetary and control mechanism, there were loopholes in the process: ring-fencing certain types of expenditure (e.g. drought relief); supplementary budgets, and donor support that bypassed the mechanism. In the final analysis, it was concluded that the reform of budgetary processes requires major cultural changes for some countries and the development of capacity for implementation.

4.2.4 Towards more effective financing of research: the interaction of revenue collection and allocation mechanisms.

Before leaving this somewhat structuralist view of the ability to finance research, we note that the source of funding affects the nature of the research that is done. Partly in response to the above problems, governments and donors have been searching for effective and innovative funding mechanisms that will result in more efficient and effective research agencies and systems. The school of "new" public administration" argues that not all public goods needs to be produced by the public sector itself and that in research we deal with many cases of "impure public goods". This opens up both investment in and delivery of quasi-public R&D results through many forms of partnership with interested producers and beneficiaries.

Echeverria and Beintema (2009) define effective financing as "one that increases the average returns of current levels of investment in agricultural research and that also attracts complementary investment from additional sources. An effective funding mechanism will then be the one that allows optimum use of research infrastructure to execute the research." Because of the under-investment in agricultural R&D, policymakers and research managers will need to find a right mix of various financing mechanisms in addition to the direct allocations from central and/or regional public budgets. As mentioned earlier that government support to agricultural R&D has stagnated or declined in a large number of countries, especially when measured in inflation adjusted terms. For a number of countries, they have hampered the performance of agricultural R&D agencies because actual disbursements had fallen behind earlier budget allocations.

Echeverria and Beintema (2009) list a number of alternative funding mechanisms which tie sources of funding and prospective beneficiaries of research closer together or permit project level control of expenditure:

1) Competitive grants, which often complement direct government budget allocations and have played an important role in mobilizing research actors around specific outputs and improving the efficiency and accountability of research outputs and actors. On the other hand, they may not be as effective as core funds in ensuring long term capacity. Furthermore, competitive

funding schemes mostly fund specific projects and often cover only their operational costs and not salaries or maintenance of the institutional infrastructure.

2) Producer check-offs and export levies, which are mostly collected through taxes raised on export or production of commercial crops. One benefit is that farmers are more involved in setting the research priorities. They finance "club goods and services", which is a form of restriction of benefits. Such para-fiscal levies come from the industry itself but may not be available in times of major crisis when they are most needed.
3) A number of agencies and countries have been successful in commercializing their research outputs, often through partnerships with the private sector. One important downside is that in many countries the revenue from commercialization goes directly into the government's treasury so there is limited incentive for research agencies to sell research outputs and services.
4) The debate about program versus project funding continues (see also the paragraph on CGIAR investment in section 2). When donors talk about shifting financing from the supply side (institutional commitment) to financing "results" it is often a prelude to a reduction in overall level of funding.

4.2.5 The Structure of the economy: the inverse of the Share of Agriculture in the Gross Domestic Product (GDP/AgGDP)

The final element underlying movements in the ARI is the inverse of the share of agriculture in gross domestic product.

In a successful transformation, the share of agriculture in GDP, the share of population in agriculture in the total population and the dependence on agriculture as the source of development finance falls. This is made possible by rising productivity in agriculture and the transfer labor to other sectors.

It should be in the transforming economies that agricultural and fiscal policy can make the breakthrough to more sustainable support for agricultural research: 1) better macro policies usually improve the opportunities for agriculture, 2) new tax bases outside the agricultural sector help remove some of the fiscal drag caused by agricultural taxation, and 3) large population in non-agriculture can make significant contributions to a declining population in agriculture.

The policy lesson for governments would be to maintain a macro economic balance and the positive environment for agriculture that it creates. Productivity increases will free both land and labor and policies should facilitate the movement of people out of agriculture as they are no longer needed on farms to feed the country. The point is not to maintain millions of small farmers but to eliminate poverty, with recourse to safety nets where agricultural and overall growth is not enough. (Valdés and Foster 2005).

SECTION 5 CHALLENGES AND ESSENTIAL INVESTMENTS

5.1 Investment options targeting special non-productivity objectives

This paper has basically argued that research oriented at enhancing farm-level productivity has being shown to have high rates of return and make generally positive contributions to environmental and social objectives. Other policy instruments can be designed (e.g. safety nets, facilitation of migration, payments for the true value of resources and ecosystem services) to ensure that society gains.

The IAASTD (2009) has identified some of the directions in which new research can make a direct impact on sustainability and social goals:

Table 4: Investment options as outlined in the IAASTD Global Report

Goal	Investment required to:	Examples
Environmental sustainability	1. Reduce the ecological impact of farming systems	Management practices; reduce use of fossil fuel, pesticides, fertilizer; biological substitutes for fossil fuels and chemicals
	2. Enhance systems that are known to be sustainable	Social science research on policies and institutions
	3. Support traditional knowledge	Non-conventional crops and breeds; traditional management systems
Hunger and poverty reduction	1. Target institutional change in organizations;	Planning with pro-poor perspective
	2. Include equity in planning and pro-poor policies	Access to resources; benefit sharing from environmental services
Improving nutrition and human health	1. Improve nutritional quality and safety of food	Co existence of obesity and micronutrient deficiency ; pesticide residue; SPS standards
	2. Control environmental externalities	Pollution, overuse of antibiotics and pesticides, on-farm diversification
	3. Ensure better diagnostic data and response to epidemic disease	Zoonotic diseases an increasing problem along with dangers of pandemics; prediction of disease and pest migration with climate change
Economically sustainable development	1. Enhance research on water use and control of pests and diseases	Both areas affected by population growth and climate change
	2. Productivity-enhancing research to save land and water as limiting factors	Total factor productivity benefits from higher yields per hectare and more crop per drop. There is need to address the most limiting factors
	3. Prices and incentives promote proper social use of resources	Pricing policies and payment for ecosystem services will make land and water use more efficient
	4. Advance basic research in genomics, proteomics, nanotechnology	Historically high rates of return to basic research; applications may spillover freely to developing countries in the future

Source: Adapted by authors from IAASTD Global Report, Table 6.2 (Gurib-Fakim et al. 2008, p 381-84) and from discussion in Chapter 8, Section 4.

5.2 Investment in basic capacity to do research and development

In this final section, we want to highlight three basic needs:

1. The need for basic studies and methodologies. Even a country that is considered too small to have a full-fledged NARS needs to invest in knowing a) What is the country's potential given its water resources, soils and climate; b) Where it can access knowledge, science and technology to realize its potential; and c) Sufficient advanced science to be a good negotiator of partnerships and purchaser of technology.
2. The need to address capacity needs in a systemic way that includes balanced growth of research institutes with universities and other stakeholders upstream and downstream.
3. The need to integrate networks at the global, regional and sub-regional levels while escaping high transactions costs and dispersion of effort.

While there are many other issues, this paper highlights these three areas of "underinvestment"

5.2.1 Basic studies and methodologies

Decisions about investment ultimately come down to two judgments: what are the possibilities of advancing knowledge and technology and what is the value to society of the new technology (Ruttan 1982)? Processes for making such decisions are increasingly a mix of supply-led analysis of expected gains prepared by scientists and a participatory (bottom-up) evaluation of the usefulness of the knowledge to clients and beneficiaries. Both the governance of the process and the nature of the evidence have to be appropriate to the level and nature of the decision to be made.

The need for basic studies is, for example, apparent in the three approaches being adopted to address priorities and strategies for global agricultural R&D (CGIAR 2009):

1. "Trust in models" includes definition and characterization of "systems" that will form the building blocks for assessing agricultural, environmental, and institutional/policy research challenges and opportunities , as well as evaluation of the nature and scale of potential R&D-induced impacts (by system) according to scenarios and parameter estimates established during the elicitation process.
2. "Trust in front-line researchers" designs and implements a science-focused elicitation of appropriate technical, institutional and social variables to be used in assessing the potential impact of research-induced change.
3. "Trust in wisdom" will draw on consultation with highly recognized research and policy leaders as reviewers and stakeholder and partner dialogues.

The above will need better tools and information in all types of areas. For example, models and spatial analysis tools can be used to identify homogeneous development domains. Modeling can substitute for expensive multilocational trials and can be used to extrapolate results for planning. However, the basic information needs to be collected and processed and results ground-truthed. The need for basic hydrological, meteorological and soils studies goes beyond the needs of "agricultural research" and needs to be provided through other budgets.

Furthermore, there are emerging challenges that are likely to grow with climate change, population growth and increasing resource scarcity. These include expansion of pests and disease and the dangers of pandemics that cut across several ministries. The current level of agricultural research on these issues can be considered "underinvestment" even if it is congruent with the current importance of the problem. Given that agricultural and land use practices contribute 32 percent of global emissions of GHG (Stern Report, 2007) the need for better understanding of agriculture's role in adaptation and mitigation is clear.

In this respect, the IAASTD highlights the need for strategic cross-disciplinary methodological research on environmental sustainability and poverty reduction:

> "The first important need for AKST investment is for social and ecological scientists working with other scientists to develop methodologies and to quantify the externalities of high and low external input systems from a monetary perspective as well as from other perspectives such as the concept of energy flows used in energy evaluations. Evidence on these externalities' potential implications on food security also needs to be analyzed."

The call is for a discussion of values as well as technical solutions. Both neoclassical economists and agro-ecologists agree that the issue of pricing of resources and the value of ecosystem services has been under-studied. The call for more research is not just about technical solutions of markets, taxes and subsidies but about the framing of the issues. This has implications for the way in which people are trained, the discussion of the following section.

5.2 2 Capacity in Agricultural Research and Higher Education

Investment is needed to reverse the general underinvestment of the last decade and meet the various political targets and prepare for the emerging challenges outlined in the previous two sections, more investment is needed. However, this presumes that there is either sufficient research capacity to address these targets or the commitment to invest in creating it. Moreover, the rate at which research capacity can grow is linked to the strength of the higher education system. In many countries, this subsystem itself requires re-tooling. Targets which project annual growth in current research expenditures of 10 percent or more need to be reviewed carefully so that good intentions do not result in wasteful expenditures that press against scarce human and institutional resources.

Various organizations and publications have expressed concern in this regard.

- An assessment of the national agricultural research and extension systems in Africa, which found many agencies with professional staff shortages, established positions remaining vacant, and an aging pool of professional research staff (FARA 2006).
- A recent study by the ASTI initiative, covering 14 countries, showed that although professionals engaged in agricultural research and higher education has increased by 20 percent during 2000/1 to 2007/8, two-thirds of this increased capacity was trained only to the BSc level (Beintema and Di Marcantonio 2009).[11]

This is a worrisome trend, especially in light of the increasing costs of postgraduate training abroad—and the diminishing relevance of these programs to Africa. This calls for an expansion of postgraduate level training in agricultural sciences (World Bank 2007).

Although the number of universities and faculties in agricultural sciences has grown substantially during the past three decades, many suffer from staff shortages, insufficient funding, declining student enrollments, outdated curricula, and a continuing focus on undergraduate studies (Beintema, Pardey, and Roseboom 1998; IAC 2004b; World Bank 2007). Donor support for training programs waned in the 1990s, and African governments have largely been unable to fund training themselves (Beintema, Pardey, and Roseboom 1998). Eicher (2006) has highlighted the sequential rather than balanced way in which agricultural research, extension and higher education have been addressed in sub-Saharan Africa. The authors agree that a balanced development of the agricultural knowledge system is needed.

There are some initiatives to address this problem. The Rockefeller Foundation established a program to train future teachers of biometrics African universities to be able to meet the demand for this basic research skill that had been neglected in recent years. A number of countries have more recently established postgraduate training programs, but in general they are still small in terms of student enrollments. Increasingly, there is recognition of the need to expand Africa's postgraduate training in agricultural sciences at both national and regional levels (World Bank 2007).

Current discussions of capacity go beyond the usual discussion of scientific and technical skills. Both the review of Agricultural Education and Training by the World Bank and reviews of research institutions mention three needs: 1) scientific capacity; 2) "soft skills" for innovative work across institutional boundaries, and 3) institutional capacity to learn and change. We have addressed the first category where MSc and PhD students are an essential part of the research infrastructure.

In the "soft skills, we find post-graduate education and evidence of personal skills that facilitate working across ministerial and sectoral boundaries. Institutional policies that facilitate cross-institute and cross-sectoral collaboration are being put in place between research institutes and universities. Furthermore, policies should be

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[11] Interestingly is that about half of the capacity increase were women resulting in an increase in the share of women in professional staff at agricultural research and higher education agencies in these 14 countries from 18 percent in 2000/1 to 24 percent in 2007/8 (Beintema and Di Marcantonio 2009).

put in place that aim to increase the participation of women Given growing concern over declining agricultural research capacity, increased participation in agricultural R&D by women is not only important for gender-balance, but also in order to tap substantial additional human resources for agricultural R&D.

It is necessary to draw attention to these processes because the training lags and transactions costs involved in taking on new agendas affect the rate at which the research system can grow without wasting resources.

5.2.3 Policy and the Institutional Architecture for Research

This final section of the paper notes that policies, institutional arrangements and the governance of research all require investments that compete with the performance of scientific and technical research. Attempts have been made to measure the productivity of social science and policy research; to establish the value of institutional changes or management improvement, and to examine the cost of governance. This is where "process is as important as the product" comes up against the assertion of the "burden of high transactions costs".

As noted in Section 5.2.1, development of a plan requires a process in which the issues are properly framed, information is brought to bear on the issues, different perspectives are integrated and some form of governance mechanism is needed to oversee implementation. We have highlighted the need for better basic information, methodologies and models to support decision-making.

The structure of global agricultural research is undergoing an important period of change. Within the CGIAR, the Alliance of research centers supported by the Group is forming a consortium that will negotiate core functions and mega-programs to be supported by a consolidated donor Fund. It is essential that this Fund provide a guaranteed core on which a sustainable system can be built. In sub-Saharan Africa, bilateral and multilateral donors are promoting the creation of regional research programs and sub-regional centers of excellence in specific areas that go beyond the previous research networks. The development of a more effective global system that meets stakeholder needs is receiving investment of time and resources.

Many emerging problems such as climate change, migratory pests, and pandemics are transboundary in nature and will require new mechanisms for dealing effectively with them.

Legal frameworks, particularly relating to intellectual property and biosafety are affecting the both concentration of research activity and access to strategic genes. New institutions such as the African Agricultural Technology Foundation are set up to facilitate access by developing countries to proprietary technology. Recent attention to biosafety has resulted in regulations that may have unintended consequences in either keeping certain potentially valuable technologies out of developing countries or concentrating ownership further in the hands of large corporations able to bear the costs of passing the process and in countries with large enough markets to justify it. Research into proper frameworks that ensure that developing countries benefit from new science and technology is a priority for investment.

5.3. Conclusion

This paper has documented key trends in global investment in agricultural R&D using the most recent data from ASTI and other sources. It has provided evidence that there has been "underinvestment" in agricultural R&D both in terms of foregone benefits and in terms of preparedness to meet established political comments to reduce poverty and hunger. Countries at all levels of development have the fiscal capacity to develop a sufficient system to participate in and benefit from what will, it is hoped, be a coherent and effective global system. By treating the establishment of legal frameworks, institutional arrangements and governance processes as "investments" we will have to keep in mind that the processes must have positive results in terms of established goals. New global challenges will require additional research investments that will only be forthcoming if adequate attention is given to the information, basic studies and human resources in national institutions of research and higher education.

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