IAASTD GLOBAL REPORT CHAPTER 8

Agricultural Knowledge, Science and Technology: Investment and Economic Returns

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Key Messages

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1. On average investments in agricultural research and development (R&D) are still growing but at a decreasing rate for the public sector during the 1990s. However, there has been an increasing diversity in investment trends among countries. Investment in public agricultural R&D in many developed countries has stalled or declined and has become a small proportion of total Science & Technology (S&T) spending. Many developing countries are also stagnating or slipping in terms of public agricultural R&D investments, except for a selected few (often the more industrialized countries). The slowing growth in agricultural R&D investment in the public sector has implications for attaining the development goals. Investments by the private sector in developed countries have been increasing, but have remained small in most developing countries. There is a knowledge gap in other areas of AKST investments such as extension, traditional knowledge, farming systems, social sciences, ecosystems services, mitigation and adaptation of climate change, and health in agriculture.

2. Funding for public agricultural R&D in developing countries is heavily reliant on government and donor contributions, but these sources have declined. Despite declining government budgets for agriculture in general, and agricultural R&D specifically, government remains the major source of funding for public agricultural R&D in most developing countries. The trend indicates that donor support for agricultural R&D has substantially declined since the mid-1980s with the majority of this smaller amount supporting global research rather than research at the country level.

3. The participation of nongovernmental agencies in agricultural R&D is increasing. AKST in the more developed world is increasingly undertaken by the private sector. Private sector research is also growing in the developing world, but is concentrated in a few countries where the private sector thinks it can make a profit. In addition, higher education agencies, NGOs, foundations, and producer groups are also increasing their participation in agricultural R&D. Still, publicly funded research in developing countries is mostly conducted by government-sponsored agencies.

4. There is evidence of under-investment in research in agriculture. Rates of Return (ROR) in AKST across commodities, countries and regions on average are high (40-50%) and have not declined over time. They are higher than the rate at which most governments can borrow money, which suggests under-investment in AKST. Although limited, evidence indicates that the investments in agricultural R&D perform equally well or better than the other public sector investments in the agricultural sector.

5. Public investments in AKST have significantly contributed to overall economic growth, but this not always has translated into poverty reduction. Public investments in AKST have in some countries significantly contributed to poverty reduction, but AKST's impact on poverty varies greatly depending on the policies, institutions, and access to resources of the country. Before AKST investments are made, distributional aspects should be explicitly taken into account. Additional analysis is required to understand better who has benefited from this additional growth and why it did not always translate into commensurate improvement of poverty and food security. Likewise, agricultural price policies and trade policies influence the distributional impacts of productivity-increasing technology, as do land and access patterns.

6. Rates of return alone are not sufficient to guide AKST investment decisions. AKST investment generates economic, social, environmental, health and cultural costs and benefits to society, some of which are considered as externalities (positive or negative) and spillovers. These noneconomic impacts are also important to society, but often not included in conventional RoR analysis due to quantification and valuation problems. The challenge is to factor these aspects into the macro-level decision-making process. RoR analysis needs to be complemented by other approaches to estimating impact of AKST investment on poverty reduction, ecosystem services and well-being. More evidence is needed on the economic and social impact of AKST investment in sectors such as forestry and fisheries, as well as in policy-oriented social science research.

7. AKST investments could have been more effective and efficient in achieving sustainable development goals had more attention been given to governance. Governance is an important determinant of mobilization of resources for AKST. It also plays a major role in allocation of resources between different components of AKST. Increased demand for effectiveness, efficiency, responsiveness to stakeholder needs, accountability and transparency is a driving force leading to changes in AKST investment decisions. High transaction costs in knowledge generation and transfer, inefficiency in resource allocation and utilization, lack of transparency, exclusion of some stakeholders, unequal access, and fear of private monopoly over technologies developed through public AKST institutions have prompted changes in AKST systems. The ability to allocate resources more effectively will also depend on a significant improvement in the capacity in public and private sectors to forecast and respond to environmental, social, and economic changes, locally and globally. This will include the capacity to make strategic technological choices, create effective public policy and regulatory frameworks, and pursue educational and research initiatives.

8. Increasing participation of nongovernmental stakeholders and more appropriate incentive systems are required to improve the effectiveness of AKST investments.

Institutional arrangements for AKST resource mobilization and allocation have, in the past, largely excluded users of research information, resulting in inefficiency and ineffectiveness in AKST investments. These arrangements have also resulted in unequal access to technologies. The demands for enhanced stakeholder participation, improved accountability and transparency are leading to institutional innovations around AKST investment governance issues. These are new and unproven arrangements, so investments will be needed to carefully monitor, evaluate and learn from the lessons in order to derive best practices. Investment is also required for strengthening capacity in order to institutionalize such practices.

9. More government funding and better targeted government investments in AKST in developing countries can make major contributions to meeting development and sustainability goals. Developing countries need to increase the intensity of AKST investments. This would involve a major increase in public sector investments, which is justified given the high rates of return to research and the evidence that AKST investments can reduce poverty. However, to do this, public investments must be targeted using evidence other than simply overall RORs, as they usually do not include environmental and human health impacts, positive or negative, or information on the distribution of costs and benefits among different groups.

10. Major public and private research and development investments will be needed in plant and animal pest and disease control. Continued intensification of agricultural production, changes in agriculture due to global warming, the development of pests and diseases that are resistant to current methods of controlling them, and changes in demand for agricultural products, will lead to new challenges for farmers and the research system. Investments in this area by the public and private sector have provided high returns in the past and are likely to provide even higher returns in the future. In addition, these investments could lead to less environmental degradation by reducing the use of older pesticides and livestock production methods; increased demand for labor, which could reduce poverty; and positively improve human health of farmers and their families by reducing their exposure to pesticides. This is an area in which public and private collaboration is essential.

11. Increasing investments in agricultural research, innovation, and diffusion of technology by for-profit firms can also make major contributions to meeting development and sustainability goals. Private firms (large and small) have been and will in the future continue to be major suppliers of inputs and innovations to commercial and subsistence farmers. They will not provide public goods or supply good and services for which there is no market, but there could be spillovers from private suppliers of technology to farmers and consumers. To make the best use of private investments in AKST, governments must provide regulations to guard against negative externalities and monopolistic behavior, and support good environmental practices, while at the same time providing firms with incentives to invest in AKST.

12. AKST investment that increases agricultural productivity and improves existing traditional agricultural and aquaculture systems in order to conserve scarce resources such as land, water and biodiversity remains as a high priority; these investments can improve livelihoods and reduce poverty and hunger. The major resource constraint on increasing agricultural production in the future will continue to be agricultural land. AKST must focus on increasing output per unit of land through technology and management practices. Water is the next most important resource constraint to agricultural production and is likely to become more of a constraint in the future. AKST resources need to be reallocated into water-saving techniques, improved policies and management techniques. Fossil fuels reserves are limited; high fuel prices and environmental concerns have recently focused attention on the need for agriculture to more efficiently use this resource. Government investment in AKST may be necessary to reduce the dependence of the agricultural sector on petroleum.

13. AKST investment to reduce greenhouse gas emissions and provide other ecosystem services is another priority investment area. AKST investments are needed to develop policies, technologies and management strategies that reduce agriculture’s contribution to greenhouse gas (GHG) emissions, and consequent global warming. This requires the development of new farming systems, which use better technologies, produce less GHG, and build on local and traditional knowledge to improve current cropping systems in order to become more sustainable. Investments are also needed to underpin policies such as payments for environmental services to farmers, which could induce the development and adoption of practices that provide stronger environmental services. Some of the agricultural technologies and policies that provide these ecosystem services can be designed to use the assets of the poor, such as labor in labor-abundant economies.

8.1 Spending and funding trends in AKST

8.1.1. Trends in agricultural R&D spending

8.1.1.1. Public sector spending

Worldwide, public investments in agricultural research and development (R&D) increased, in inflation-adjusted terms, over the past two decades from an estimated $15 billion in 1981 to $23 billion in 2000 (in 2000 international dollars); an increase of about one-half (Table 8.1 and Figure 8.2).[1] [2] The share of the developing countries as a group have increased considerably over the years; during the 1990s the group invested more on public agricultural R&D than the combined total in the industrialized world. Investments by Asia and Pacific countries as a group grew relatively resulting in an increasing share of the global total; the regional share was 33% in 2000 compared to only 20% in 1981. Most of this growth took place during the late-1990s. In contrast, the corresponding share for sub-Saharan Africa continued to decline, falling from 8 to 6% of the global total between 1981 and 2000.

Public agricultural R&D has become increasingly concentrated in just a handful of countries. Among the rich countries, the United States (US) and Japan accounted for 54% of public spending in 2000; about the same as two decades earlier. Three developing countries, China, India, and Brazil, spent 47% of the developing world’s public agricultural research total, an increase from 33% in 1981. Meanwhile, only 6% of the agricultural R&D investments worldwide were conducted in 80 countries that combined had a total to more than 600 million people in 2000.

[Insert Table 8.1]

[Insert Figure 8.1]

Growth in inflation-adjusted spending has slowed down since the 1970s when most regions experienced high growth rates (Figure 8.2). Overall spending in the Asia and Pacific region increased with an annual growth rate of 3.9% during the 1990s; lower than the regional growth in the 1980s (Beintema and Stads, 2006). However the average growth rate in total spending in China and India increased during the 1990s. This was in part due to an increase in total agricultural R&D spending in both countries during the second half of the 1990s, which reflects

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[1] Public includes government, higher education, and nonprofit.

[2] Unless otherwise stated, financial figures in this subchapter have been expressed in inflation adjusted ‘international dollars’ using the benchmark year 2000 and purchasing power parities (PPPs). 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. Using PPPs as conversion factors to denominate value aggregates in international dollars results in more realistic and directly comparable agricultural research spending amounts in countries than if market exchange rates are used. This is because the latter tends to underestimate the quantity of spending used in economies with relatively low prices while overestimating the quantity for those countries with high prices. This is particularly a problem when valuing something like expenditures on agricultural R&D, where normally about two-thirds of the resources are spent on local scientist and support staff salaries and not on capital or other goods and services that are normally traded internationally.

new government policies to revitalize public agricultural research and improve its commercialization prospects. Two other regions, Latin America and the Caribbean, and West Asia and North Africa, both experienced relative less growth in total spending during the 1990s (2.0 and 3.3%, respectively). In contrast, the increase in total spending in sub-Saharan Africa decreased in the 1990s from 1.3 to 0.8% compared to a decade earlier. An even more severe drop in spending is found in many sub-Saharan African countries. In about half of the 24 countries for which time series data were available, the public sector spent less on agricultural R&D in 2000 than 10 years earlier.

[Insert Figure 8.2]

Noteworthy is the decline in total agricultural R&D spending among the rich countries; during the 1990s total spending declined by an annual rate of 0.6%. Specifically Japan, and to a lesser degree a few European countries, reduced their investments in agricultural research. Support for publicly performed agricultural research among rich countries has declined over a long period in time due to changes in government spending priorities and a shift toward privately performed agricultural R&D. These slowdowns in agricultural R&D spending may curtail the future spillovers of technologies from rich to poor countries (Pardey et al., 2006b) (8.2.7).

The allocation of resources among various lines of research is a significant policy decision and takes place at different levels and, in theory (although not always in practice), follows the priorities set across commodity and multidisciplinary research programs. More than one half of the full-time equivalent (fte) researchers in a sample of 45 developing countries conducted crops research while 15% focused on livestock and 8% on natural resources research (Table 8.2). Asia-Pacific had relatively less livestock researchers (13%) than sub-Saharan Africa and Latin America (18% each). Forestry, fisheries, and postharvest accounted for 4 to 6% each. The remaining 9% of the research staff in the developing world conducted research in other agriculture related sciences.

For all three regions, fruits and vegetables are among the major crops being researched. Unsurprisingly, rice is a relatively important crop in the Asia-Pacific region while maize has high importance in Latin America.

[Insert Table 8.2]

The allocation of resources above does not cover the full scope of AKST, e.g., areas of importance in the future may include bioenergy, climate change, transgenics, and biodiversity. The Stern Review on the Economics of Climate Change (Stern, 2007) concludes that an annual investment of 1% of global GDP is required to mitigate the negative effects of climate change.

Although economists argue whether the figures in the Stern review are right, most agree that the cost of failing to tackle climate change will so vastly outweigh the cost of succeeding that further refinement of the calculations are largely irrelevant to the political and investment choices that must be made now. Among these could be the creation of incentives for investment in low-carbon technologies.

Some limited information on the budget levels in bioenergy R&D in OECD countries is available through the International Energy Agency (IEA). Total R&D budgets for bioenergy are estimated to have increased almost three-fold since 1992 to a total of $271 million (in 2005 international dollars) in 2005. Despite the increased interest in renewable energy and energy-saving technological innovations to mitigate climate change, total budgets on energy R&D in OECD countries, in adjusted terms, have remained flat since 1992. As a result, the share of bioenergy R&D in total energy R&D investments also grew almost threefold during 1992-2005 (IEA, 2006).

In this chapter, public agricultural research includes research performed by government, higher education, and nonprofit agencies. There are substantial differences among countries and between regions in the structure of the public research sector (Figure 8.3). Public research in the United States is done mainly in state agricultural experiment stations located primarily in colleges of agriculture and in federally administered, but often regionally located, laboratories. A large share of public agricultural R&D in Asia-Pacific and Latin America is conducted by government agencies (about three-quarters of the total). This is similar to the government agency share in a 27-country sub-Saharan African total. A small, but growing proportion of public agricultural research in Latin America and sub-Saharan Africa is conducted by nonprofit institutions. Nonprofit institutions are often managed by independent boards not directly under government control. Many are closely linked to producer organizations from which they receive the large majority of their funding, typically by way of taxes levied on production or exports (see 8.3.3).

[Insert Figure 8.3]

8.1.1.2. Private sector spending

Agricultural R&D investments by the private sector have grown in recent years and in the industrialized world now account for more than half of the sum of the public and private research investments. Although private sector performed agricultural R&D appears to have increased in some developing countries, overall the role of the private sector is still small and will likely remain so given weak funding incentives for private research. In addition, many of the private sector R&D activities in developing countries focus solely on the provision of input technologies or technological services for agricultural production with most of these technologies produced in the industrialized world.

[Insert Box 8.1]

Private sector share of total agricultural research investments are estimated at 37% (Table 8.3). Most of which was performed in the industrialized countries (94%) where they spent on average more on agricultural research than the public sector. In contrast, only 8% of total spending in the developing world was conducted by private firms with the remaining 92% by public agencies. In the developing world, private sector involvement in agricultural research was relatively higher in the Asia and Pacific region with an average of 11% in 2000 (Pardey et al., 2006a)

[Insert Table 8.3]

Private sector involvement in agricultural R&D in OECD countries differs from one country to another. In 2000, more than 80% of total agricultural R&D spending in Belgium, Sweden, and Switzerland was done by the private sector. In contrast, private sector shares were below 25% in Australia, Austria, Iceland, and Portugal that same year. Private and public sectors are involved in different types of research. In 1993 only 12% of the private research in five industrialized countries (Australia, the Netherlands, New Zealand, UK, and the US) focused on farm-oriented technologies compared to 80% in the public sector. Food and other postharvest accounted for 30 to 90% of agricultural R&D investments in Australia, Japan, the Netherlands, and New Zealand. Chemical research accounted for 40 and 75% of private research in the UK and US, but was less important in Australia, and almost negligent in New Zealand (Alston et al., 1999).

A survey of seven Asian countries during the mid-1990s showed that the share of private investments had grown in three countries (China, India, and Indonesia) even more than the increases in public sector investments (Pray and Fuglie, 2001). However, this growth was uneven across subsectors. Total investments in the agricultural chemical industry in Asia, which includes mostly pest control chemicals and, to a lesser extent, fertilizer and biotechnology, tripled during mid-1980s and mid-1990s. Private spending on livestock research also grew considerably, but growth was substantially slower in other subsectors such as plantation crops and machinery. Both locally-owned and multinational firms played similar important roles in agricultural R&D. Multinational firms accounted for an average of 45% of total private research spending in the seven Asian countries, but with substantial differences among countries. Almost all research in China by truly private firms (rather than government-owned, commercial firms) was by multinational firms in the mid-1990s while in Malaysia only 10% of private sector investment from multinationals. Foreign firms were concentrated in the agricultural chemical and livestock subsectors; i.e., those with the highest growth rates (Pray and Fuglie, 2001).

In SSA, only 2% of total agricultural R&D is conducted by the private sector.[3] Almost two-thirds of the region's private research was done in South Africa. Most firms in SSA have few research staff with low total spending and they focus on crop improvement research, often export crops (Beintema and Stads, 2006).[4] Similarly as in the Asian region, multinationals and locally owned companies play a similarly important role. Given the tenuous market realities facing much of African agriculture, it is unrealistic to expect marked and rapid development of locally conducted private R&D. Yet there may be substantial potential for tapping into private agricultural R&D done elsewhere through creative public-private joint venture arrangements (Osgood, 2006).

In 2000, total investments in all sciences conducted by the public and private sectors combined were over $700 billion (in 2000 international prices) (Table 8.4). The regional shares in the global total differ substantially from the shares in agricultural R&D spending. Industrialized countries combined accounted for about 80% of total science and technology (S&T) spending while SSA's share was less than one percent. There are also considerable differences in the shares of public and private agricultural R&D spending in total S&T spending. Agricultural R&D spending in SSA accounted for more than one-third of the region's total science spending while in the other regions in the developing world these shares were considerably lower (9 to 12%). In the industrialized world spending in agricultural R&D was only 4% of the total S&T investments.

[Insert Table 8.4]

8.1.1.3. Intensity of research

In order to place a country's agricultural R&D efforts in an internationally comparable context, measures other than absolute levels of expenditures and numbers of researchers are needed, e.g., the intensity of investments in agricultural research. The most common research intensity indicator is a measure of total public agricultural R&D spending as a percentage of agricultural output (AgGDP).[5] The industrialized countries as a group spent $2.36 on public agricultural R&D for every $100 of agricultural output in 2000, a large increase over the $1.41 they spent per $100 of output two decades earlier, but slightly down from the 1991 estimate of $2.38 (Figure 8.4). This

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[3] The private sector does, however, play a stronger role in funding agricultural research, as opposed to performing research itself. Many private companies contract government and higher-education agencies to perform research on their behalf.

[4] Examples are cotton in Zambia and Madagascar and sugar cane in Sudan and Uganda.

[5] Some exclude for-profit private agricultural research expenditures when forming this ratio, presuming that such spending is directed toward input and postharvest activities that are not reflected in AgGDP. For reasons of consistency with these other studies, we excluded national and multinational private companies (but not nonprofit institutions) from the calculated intensity ratios.

longer-run increase in research intensity is in stark contrast to the group of developing countries; this group has seen no measurable growth in the intensity of agricultural research since 1981. In 2000, the developing world spent just 53 cents on agricultural R&D for every $100 of agricultural output. Agricultural output grew much faster in the developing countries as a group than in the industrialized countries. As a result, intensity ratios remained fairly stable for the developing regions as a group despite overall higher growth rates in agricultural R&D spending in the developing countries, and the intensity gap between rich and poor countries has widened over the years. More than half of the industrialized countries for which data exists have higher research intensity ratios in 2000 than they did in 1981 (and the majority of them spent in excess of $2.50 on public agricultural R&D for every $100 of AgGDP). Most countries in our Asian and Latin American sample (9 out 11 Asian countries and 8 out of 11 Latin American countries) increased their intensity ratios over the 1981-2000. Only 6 of the 26 countries in SSA had higher intensity in 2000 compared to two decades earlier.

[Insert Figure 8.4]

The large and growing gap between developing and industrialized countries as groups is even larger in terms of total, i.e., public and private, agricultural research spending (Figure 8.5). In 2000, the intensity of total spending was nine times higher in rich countries than in poor ones; and four times higher than when only public research spending is used as the basis of the intensity calculation.

[Insert Figure 8.5]

Other research intensity ratios can be calculated as well. The industrialized countries as a group spent $692 on public agricultural research per agricultural worker in 2000, more than double the corresponding 1981 ratio (Table 8.5). The developing countries as a group spent just $10 per agricultural worker in 2000, substantially less than double the 1981 figure. These differences are not too surprising considering that a much smaller share of the workforce in industrialized countries is employed in agriculture, and the absolute number of agricultural workers declined more rapidly in these countries than it did in the developing countries.

Expressing agricultural R&D spending per capita gives a different trend than the other two intensity calculations. Spending per capita for the industrialized countries as a group increased substantially from 1981 to 1991, but has declined since then. About half of the rich countries experienced declining levels of spending per capita; Japan most severely due to the sharp decline in agricultural R&D spending in that country during the 1990s. Spending per capita levels are much lower for the developing countries. Most countries, especially those in Africa, spent less than $3 per capita in 2000; while 59% of the industrialized countries invested more than $10 per capita in 2000. In contrast to the group of rich countries, agricultural R&D spending per capita for the developing countries as a group continued to increase from $2.12 per capita in 1981 to $2.72 in 2000. The exception is SSA where spending per capita has declined during the 1981-2000 period.

[Insert Table 8.5]

8.1.1.4. International agricultural R&D

International agricultural research efforts began in the middle of the 20th century when the Ford and Rockefeller Foundations placed agricultural staff in developing countries to collaborate with national scientists. These efforts evolved into the establishment of four international organizations during the 1960s. In 1971 these centers formed the basis for the Consultative Group on International Agricultural Research (CGIAR or CG). Currently there exist 15 centers (see Chapter 2.2.4 for a detailed historical overview), with a total budget of US $415 million in 2004—US $384 million in 2000 prices. Although the CG system has played an important role in the Green Revolution, it only spends a small part of total of the global agricultural R&D investment. In 2000, the CG represented 1.6% of the US $23 billion global public sector investment in agricultural R&D (from 0.8% in 1981); 2.9% when spending by the rich countries is excluded (Pardey et al., 2006b).

After an initial expenditure of US $7 million in 1960, total spending rose to US $13 million per year in 1965, in inflation-adjusted terms. By 1970, the four founding centers (IRRI, CIMMYT, IITA, and CIAT) were allocated a total of US $15 million annually. During the next decade, the total number of centers increased to twelve, and the funding per center increased. This led to a tenfold increase in nominal spending to US $141 million in 1980. During the 1980s, spending continued to grow, more than doubling in nominal terms to reach US $305 million in 1990. The rate of growth had slowed but was still substantial. In the 1990s, however, although the number of centers still grew, funding did not grow enough to maintain the level of spending per center and growth rates declined. Since 2000, funding has grown in total but with a continuing trend toward earmarked support for specific projects and programs of research involving multiple centers and other research providers outside the CG. In 1980, the share of the four founding centers of total CG spending was 54%, but by 2004 it had slipped to only 36% (Pardey et al., 2006b).

8.1.2. Determinants of public and private R&D investments

A conceptual model of the factors that influence these investments is needed to make a critical assessment of research investments trends.

8.1.2.1. Determinants of public research

In the absence of public intervention, private firms will under-invest in research when the output of that research has the characteristics of a public good—that is, the outputs of research are often non-rival and non-excludable. Because of the public goods nature of research, the social benefits are much higher than the private benefits, and hence the justification for public intervention. While many public investments have high social benefits, public investment will only be justified if the return is higher than other forms of public investment. A review of the RORs to research (see 8.2) shows that public investments do have high payoffs, often 40 to 50% or more. Considering that private companies and governments usually can obtain credit at interest rates below 10% and the public RORs on other types of government investments are considerably lower than 40%, these returns are very high.

Whereas studies that show high social RORs to research investments may convince economists that agricultural research is a good investment, most policy makers who actually do not appear to have been sufficiently convinced that these high social RORs warrant large investments. Rather, public investments in agricultural research respond to many of the same forces that influence the amount and direction of private research (Hayami and Ruttan, 1985).

Public agricultural R&D increases when there are advances in basic knowledge and technology in fields such as biology, chemistry, engineering, and information technology that increase the possibility of an innovation or reduce the cost of developing an innovation. This is referred to as an increase in technological opportunity. The discovery of dwarfing genes in rice and wheat created the opportunity for plant breeders around the world to produce many new types of varieties that would respond to higher doses of nutrients and water. These opportunities increased the potential return to research and led to major increases in public sector plant breeding research around the world. Likewise, the tools of biotechnology have created a major shift in the innovation possibility curve for plant and animal breeding, pest control, and abiotic stress tolerance, and many governments have again responded by increasing their investments in research (Box 8.1).

Changes in the demand for agricultural products by farmers and consumers induced public R&D investments (Hayami and Ruttan, 1985). Historically in Asia, population and per capita income increases increased the demand for basic food grains such as rice; farmers were unable to increase production rapidly due to limited land and agricultural prices increased. Private firms did not attempt research to fulfill this demand because profits were projected to be insufficient. When farmers and consumers were sufficiently well organized and demanded a solution, Asian governments invested in agricultural research. For example, following World War I Japan had very high rice prices and consumers demanded cheaper food, but Japanese farmers had no land for expansion. The government responded by investing in research that eventually led to nutrient-responsive rice varieties; this resulted in biological technologies and inexpensive fertilizers increased yields per unit of land. In the late 1950s, national governments, nonprofit foundations, and aid donors responded in a similar manner to the food crisis and high food prices caused by rapid population growth in other Asian countries and invested in the international agricultural research centers and the national agricultural research systems.

Demand for solutions to specific problems, such as a new disease or pest or the shortage of a key input (such as the aforementioned land shortages in Asia and resulting development of land-saving technologies), also lead to public sector research investments and can direct the allocation of investments. The worldwide public sector response to Avian Influenza is a current example. . There are also demands that receive insufficient investments, for example, research on diseases such as malaria or investment in appropriate agricultural technologies for poor people. Whether these factors will actually lead to more or less R&D investments by governments depends on the structure of the government, its ability to raise money, and the power of various interest groups to influence government spending decisions.

Some governments are more committed to R&D as a major tool for economically sustainable development. They will put a larger share of their budget into research of all types including agriculture (Anderson, 1994). The structure of the research system will also influence the size and direction of agricultural research (Morris and Ekasingh, 2002). Some governments have structured their R&D system to be more responsive to the demands of the agricultural sector while others are more responsive to demands of the food consumers, agricultural scientists, or foreign aid donors. The size and power of different interest groups can also have a major impact on the size and direction of agricultural R&D. Commercial farmers can push their governments for large investments in research that is likely to concentrate on reducing costs crop production or increasing demand. If the textile industry is strong, research will be focused on bringing down the cost of cotton. Strong consumer lobbies are likely to lead to research that lower food prices. In countries where private research on topics such as maize breeding or poultry breeding become strong, the companies that are doing this research will lobby for government to stop competing with them in the applied research of the development of new varieties and to move upstream to work on things like germplasm enhancement (Pray and Dina Umali-Deininger, 1998; Pray, 2002).

8.1.2.2. Determinants of private research

For private firms agricultural R&D is an investment that they hope will increase their profits. The returns to private research improve in the presence of sizable expected demand for the research products, the availability of exclusion mechanisms to appropriate part of the benefits from the new product or process, favorable market structure, and a favorable business environment that permits efficient operations (Pray and Echeverría, 1991). The profitability of private research also depends on technological opportunities (Pray et al., 2007).

Potential demand for inputs and consumer products developed through research, and thus market size, varies among regions depending on the size of the population, the purchasing power of the prospective buyers, local agroclimatic conditions, and sectoral and macroeconomic policies that influence input and output prices. In 2000, for example, the size of the global crop protection market was estimated to be US $28 billion (Syngenta, 2004), and consequently the first generation of biotechnology traits were designed to capture a portion of this market by either substituting for, or enhancing the productivity of, existing chemicals. Firms introduced these traits into crops with large markets, thereby enhancing their ability to extract rents.

Changes in the incentive environment affect the demand for research services and the speed at which countries can adopt new agricultural innovations. Macroeconomic and sectoral policies alter the relative profitability of agricultural activities which in turn affect the expected profitability of adopting different agricultural innovations, as well as the capacity of different segments of the farm community to acquire the new technologies (Anderson 1993). The effectiveness of agricultural support services delivery (public and private), in particular agricultural extension, and rural infrastructure (roads, markets, irrigation) will also have a major influence on the types and range of technologies introduced and the speed of adoption. Bilateral and multilateral trade agreements and phytosanitary legislation reshape trading rules and influence market access and thus potential market size (Spielman and von Grebmer, 2004).

Government policies that affect the local business environment directly influence the returns to private research. Examples of such policies are government marketing of inputs that reduce the market share of private firms and licensing and investment regulations that favor smaller firms over larger firms (Pray and Ramaswami, 2001).

Appropriability is an important precondition for private for-profit firms to participate in agricultural research. If firms can not capture (appropriate) some of the social benefits of their research, they cannot make profits on their research investments and will stop investing (Byerlee and Fischer, 2002). To capture some of the benefits from the innovation, the innovating firm must be able to prevent imitators from using the innovation. The ability to do this is a function of the characteristics of the technology, the laws on intellectual property and their enforcement, the structure of the industry that is producing the technology and the industry that is using it. The legal means of protection against unauthorized use include patents, plant breeder's rights, contracts, and trademarks. They also control their use by keeping inventions or key parts of their inventions secret, which in some countries is protected by trade secrecy law. These legal means tend to give limited protection in developing countries (Pray et al., 2007).

Inventors can also protect their inventions by biological means such as putting new characteristics into hybrid cultivars or including other technical means to prevent copying. In the case of hybrids the seeds will yield 15 to 20% less. This is usually sufficient incentive for farmers to purchase new seeds each year. In the case of genetic use restriction techniques some of the proposed techniques (none are in commercial use yet) would use genetically engineered crops, which would produce sterile seed unless the seed had been treated with a specific chemical. The degree of appropriability achieved is a function of the strength of intellectual property laws, and other factors causing farmers to prefer to purchase a technology, the degree to which government agencies can enforce the law which exist, the structure of industry that reduces the cost of enforcing IPRs, and the technical capacity of firms to balance the value they can charge farmers for their products, which ultimately depends on the farmers receiving more value than they pay for, protect their varieties through the use of hybrids (Pray et al., 2007).

Private research investments are also determined by the potential costs of the agricultural research program and the associated risks (Pray and Echeverria, 1991). The cost of research is the combination of quantity and price of research inputs, the number of years needed to develop a new technology, and available knowledge in the area of science. Such costs decrease with the supply of research inputs, the presence of a favorable business environment, the stock of existing knowledge and technology, and available human capital for conducting research activity. Research costs increase in the presence of anti-competitive markets or when firms have to meet certain regulatory requirements.

The supply of research inputs and thus their price depends on the availability and accessibility of research tools and knowledge, many of which are produced by the public sector. For example, private breeders, to add desirable traits to new private varieties, may use improved populations of crop germplasm developed by public research programs as parent material. The advances in biotechnology knowledge have led to a significant increase in private investment in agricultural research in the United States and Europe over the past two decades. Greater private sector R&D implies that the marginal cost of applied agricultural research will decline as firms take advantage of economies of scale and scope. However, the concentration of key research inputs amongst a few firms raises the possibility that the cost of conducting research for those who do not have access to such technologies will increase (Pray et al., 2007).

The domestic supply and quality of human capital, a key input to the research activity, influences the level of research investments. In the Philippines, the availability and low cost of hiring local well-trained research personnel encouraged some multinational firms to transfer their research programs to teams of Filipino scientists (Pray, 1987). The domestic supply of skilled personnel is heavily dependent on the level and composition of public and private expenditures on education. Several aspects of the business environment affect the level and productivity of research costs. Industrial policy can influence the degree of market concentration, the intensity of competition, and the prices of research inputs and outputs. Various government incentive programs, such as government contracts for new products and processes, grants and concessional loans, technical information services, and tax incentives, reduce research costs. Indirectly, the development of capital markets makes it easier for firms to raise funds for research (for example, venture capital). Bilateral and multilateral agreements also improve trade opportunities by facilitating access to intermediate technologies.

Regulation such as product quality standards, quality testing regulations and seed certification procedures can greatly increase the costs of commercializing research output and they can delay the adoption to new technology which reduces the incentive to innovate and reduces the benefits to farmers. Regulations that have been put in place in many countries to ensure that products developed using biotechnology are environmentally benign and safe for human consumption are necessary to gain consumer acceptance, but they have greatly increased the cost of developing and releasing transgenic plant varieties. For example, one seed company spent US $1.6 to 1.8 million to obtain regulatory approval for Bt cotton in India. This is more than the annual research budgets of most Indian seed companies. As a result, only the largest companies can afford to attempt to commercialize genetically modified crops (Pray et al., 2005). Bangladeshi regulations that required irrigation pumps and diesel engine meet efficiency standards of wealthy countries delayed the commercialization of inexpensive Chinese irrigation equipment and slowed the spread of high yielding rice varieties by 5 to 10 years (Gisselquist et al., 2002)

8.1.3. Investments in other AKST components

Investment data for other AKTS components, such as education and mainstreaming traditional knowledge, are difficult to obtain.

Due to the public good attributes of extension services, it not surprising that the great majority of official extension workers worldwide are publicly-funded and most extension is delivered by civil servants. Universities, autonomous public organizations, and NGOs deliver perhaps 10% of extension services, and the private sector may deliver another 5% (Anderson and Feder, 2003).

The structure and function of national extension systems continue to change, particularly as the level and source of funding,—especially public funding, changes across different countries. In many countries, there is a continuing effort to shift the cost of extension to farmers, although these different approaches to privatizing extension or to increase cost recovery by public extension systems have met with different levels of success (Anderson, 2007), private sector involvement remains small..

Given the numbers of extension personnel and the likely costs incurred in the different country contexts, agricultural extension investment is of the same order of magnitude (although likely lower) as the agricultural research world presented in expenditure terms (Table 8.1); so it is surprising that it has been subject to relatively little critical data collection and analysis. In contrasting differences between developing and more industrialized countries, one feature is the even more extreme differentiation between public and private entities; however, the situation is not fully clear (World Bank, 2006; Anderson, 2007).

8.1.4. Funding agricultural R&D in developing countries

Although various new funding sources and mechanisms for agricultural research have emerged in recent decades (see 8.3), the government remains the principal source of funding for many developing countries. For example, the principal agricultural research agencies in the largest countries (in terms of agricultural R&D investments) such as Brazil, China, India, Mexico, Nigeria, and South Africa are still mostly funded by the government. In contrast, the principal agencies in a number of countries have been able to diversify their sources of support through contract research (for example, Chile and Cote d'Ivoire) or a commodity tax on agricultural production or export (for example, Uruguay, Malaysia, Colombia) (ASTI, 2007).

Bilateral and multilateral funding has been an important source for agricultural R&D for many countries. Since 1970, both multilateral and bilateral assistance grew in real terms, but began to decline after the early 1990s to only US $51.2 billion by 2001. In recent years, ODA has increased again (Table 8.7). After several decades of strong support, international funding for agriculture and agricultural research began to decline around the mid-1980s. This decrease is mostly related to the significant increase in the share of ODA spent on social infrastructure and services (FAO, 2005a). Data on the sectoral orientation of aid are available for bilateral funds only. The agricultural component of bilateral assistance grew steadily and accounted for 16% in 1985, declining thereafter to 4% in 2003. Regionally the largest proportional reductions in assistance occurred in Asia. ODA to agriculture halved in SSA and decreased by 83% in South and Central Asia during the period 1980-2002 (FAO, 2005a).

[Insert Table 8.6]

Data on aggregate trends of donor funding for agriculture and agricultural research are unavailable, but information on agricultural R&D grants and loans from the World Bank and the United States Agency for International Development (USAID) is accessible. The amount of funding that USAID directed toward agricultural research conducted by national agencies in less-industrialized countries declined by 75% in inflation-adjusted terms from the mid-1980s to 2004. Again, Asian countries experienced the largest losses, but funding to Africa and LAC was also cut severely (Pardey et al., 2006a). Over the past two decades, World Bank lending to the rural sector has been erratic, but after adjusting for inflation, the general trend has been downward as well. The exception is the large amount of lending in 1998, which resulted mostly from loans with large research components approved for India, China, and Ethiopia (Pardey et al., 2006a).

There appears to be no single cause for the decline to the donor support for agriculture between1980-2003, although the following factors could have contributed (Morrison et al., 2004):

- Loss in donor confidence in agriculture;
- Perceived high transaction costs and complexities in agricultural investments;
- Changes in definitions in aid statistics;
- Weaker demand for assistance to agriculture from many developing country governments;
- Changes in development policy and approaches to more market led approaches;
- Shifting emphasis towards the education and health sectors;
- Changes in aid modalities, such as the movement away from the green revolution technologies of the 1960s to 1980s and the integrated rural development projects of the 1980s and 1990s, to the current sector wide approaches and support to poverty reduction strategies (Eicher, 2003).

However, science and the use of new ideas have been acknowledged by many as being important in delivering the MDGs and there has been renewed interest by the donor community on the role of agriculture in promoting economic growth and poverty reduction. In addition, a number of new funding sources such as the Bill and Melinda Gates Foundation have become available.

A number of developing countries, especially in SSA, have become increasingly dependent on donor funding. Although the share of donor contributions in total funding for SSA agricultural R&D has declined slightly in the later half of the 1990s (Figure 8.6). These declines resulted in part from the termination of a large number of World Bank projects in support of agricultural R&D or the agricultural sector at large. Donor contributions (including World Bank loans) accounted for an average of 35% of funding to principal agricultural research agencies in 2000. Five years earlier, close to half the funding of the 20 countries for which time series data were available was derived from donor contributions. These regional averages mask great variation among countries. In 2000, donor funding accounted for more than half of the agricultural R&D funding in 7 of the 23 sample countries. Eritrea, in particular, was highly dependent on donor contributions. In contrast, donor funding was virtually insignificant in Botswana, Malawi, Mauritius, and Sudan (under 5%) (Beintema and Stads, 2006).

[Insert Figure 8.6]

Since the International Conference on Financing for Development convened in Monterrey 2002, the share of aid to least developed countries in donor gross national income (GNI) has increased to 0.08%, and longer term commitments to reach 0.7% have been made by donors but it is still short of the target, and the level of the external assistance to agriculture has remained unchanged (FAO, 2005a). However the situation continues to change.

To improve upon past efforts to achieve food security, the New Partnership for Africa's Development (NEPAD) has developed the Comprehensive Africa Agriculture Development Programme (CAADP). In line with CAADP’s goal of improving agricultural productivity with an average of 6 percent per year, is the recommendation to double the region’s intensity in agricultural research by 2015 (IAC, 2005). Doubling Africa’s agricultural research intensity ratio from 0.7% in 2000 to about 1.5% by 2015 would require an average annual growth rate in agricultural R&D spending of 10% (Beintema and Stads, 2006). This goal seems unlikely considering that growth in Africa’s R&D spending averaged 1% per year during the 1990s as reported earlier. There is no evidence that governments and donor organizations have substantially increased their funding to agricultural research since the late 1990s and it is unlikely that the high level of donor support will continue indefinitely.

8.2 Impacts of AKST Investments

The purpose of undertaking and impact assessment of agricultural AKST depends on when the assessment is done in relation to the project cycle. It can be undertaken before initiating the research (ex-ante) or after completion of the research activity (ex-post). Ex-ante impact studies (proactive) can indicate the potential benefits from research and, therefore, assist managers in planning, priority setting and, consequently, in allocating scarce resources. They can also provide a framework for gathering information to carry out an effective ex-post evaluation. Ex-post studies (reactive) can demonstrate the impacts of past investments in achieving the broader social and economic benefits. Most commonly, ex-post impact assessments are carried out because decision makers and research managers usually require them as a pre-condition for support. They are undertaken to (i) help managers by providing better and more convincing advice on strategic decisions about future AKST investment; (ii) make scientists and researchers aware of the broader implications, if any, of their research; (iii) Identify weak links in the research to affect pathways; and (iv) better inform managers on the complementarities and tradeoffs between different activities within a research program (Maredia et al., 2001).

8.2.1. Conceptual framework

AKST investments generate different outputs including technologies of various types, management tools and practices, information, and improved human resources. In the literature the term impact is used in many different ways (DANIDA, 1994; Cracknell, 1996; Pingali, 2001). In this chapter we refer to impact of AKST investment as the broad long-term economic, social and environmental effects (SPIA, 2001). Impact assessment is a process of measuring whether a research program has produced its intended effects, such as increase in production and/or income, improvement in the sustainability of production systems (Anderson and Herdt, 1990) or improvements in livelihood strategies. In any comprehensive impact assessment, it is necessary to differentiate between the research results (outputs) and the contribution of research to development efforts (outcomes) and both aspects should be addressed simultaneously. A conceptual framework for assessing impacts (Figure 8.7) incorporates the multifaceted consequences of AKST investment in terms of both institutional and developmental impacts including spillover effects. This framework recognizes the multiple impacts of AKST investments and the need for multi-criteria analysis as well as RORs earned by such investments.

A comprehensive impact assessment requires multiple techniques using both qualitative and quantitative assessment. This means that not all impacts associated with AKST investment can be quantified and valued in monetary terms, although new techniques are emerging that could complement ROR measures especially in valuing social and environmental consequences (Anandajayasekeram et al., 2007). There are also concerns about exclusively reliance on ROR for decision making. The portfolio approach considers the internal rates of return across projects rather than considering them in isolation and aims to maximize the expected returns to the entire AKST investment. Despite its shortcomings the ROR to investment is the most commonly used measure to compare the relative performance of investments and a frequently used measure of research efficiency. Most literature on impact assessment of AKST investment is largely based on RORs and these studies are assessed in the following sections (Anandajayasekeram et al. 2007; Alston et al., 2000a).

[Figure 8.7]

8.2.2. Economic impact assessment

Economic impact measures economic benefits produced by an AKST project or program and relates these benefits with the economic costs associated with the same project or program. This information is used to compute measures like benefit-cost ratio, internal rate of return (IRR) and net present value of benefits (NPV). Economic impact evaluations are intended to measure whether a project or program actually had (or expected to have) an economic impact and compare this impact with project or program costs. They do not measure whether it was designed or managed and executed optimally (Evenson, 2001). An AKST program may have other relevant impacts, such as social (poverty reduction, enhanced nutrition, equity) and environmental effects; and benefits of the research may be distributed in different ways. Some nonmarket impacts such as environmental or health effects of AKST could potentially be given economic value and incorporated into economic analysis. Measurement in these cases is, however, usually more difficult than the measurement of economic impacts that are observable in product or input markets. These attributes should be accounted for in some way, even if economic values cannot be ascertained, when a more realistic evaluation of research impacts is required. In any meaningful empirical analysis, a multi-criteria approach is recommended to assess the impact of AKST assessment.

The literature on economic impact studies includes a wide range of levels of impact analysis. The economic basis for government involvement in agricultural AKST is the perception of market failure leading to private underinvestment (Nelson, 1959; Arrow, 1962; Alston and Pardey, 1998). The appropriate criterion for the assessment of policy aiming to correct market failure is the effect on net social benefits, and this can be expressed as a social rate of return (ROR) to public investment in agricultural AKST (Alston et al., 2000a).[6]

8.2.3. Methodological limitations of impact measurements

Although there have been significant developments in impact assessment methodologies a number of issues still need further attention. Key among these are the issues of attribution, incrementality, causality, defining counterfactual situations, and estimating economic impacts for organizational and institutional innovation and social science and policy research. The issue of counterfactual situations refers to the significant problem of determining what the pattern of productivity growth would have been in the absence of a particular research investment (Alston and Pardey, 2001). This is associated with dynamics of productivity factors even in the absence of AKST investment. AKST programs operate in environments in which ordinary or ‘natural’

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[6] In the literature the terms financial, economic and social rates of returns mean different things, but in this chapter the term economic rate of return and social rates of return are used interchangeably. This is because the various meta-analyses do not explicitly make this distinction.

sequences of events influence outcomes. Impact assessment and ROR estimates must arrive at estimates of net intervention effects, i.e. they should measure the changes attributable to the intervention.

Causality is another issue that merits attention. In measuring the impacts of AKST investments, it is important to ensure that the impacts measured are the results of the technologies and activities undertaken within the program/project. However, as one moves from the direct product/output to broader economic, social and environmental effects, the chain of causal events is too long and complex, and the variables affecting ultimate outcomes are too numerous to permit the identification and measurement of impacts of specific interventions (Biggs, 1990; Rossi and Freeman, 1993). This is further complicated by the time lag between initial investment and reaping its return.

Attribution problems arise when one believes or is trying to claim that a program has resulted in certain outcomes, and there are alternative plausible explanations. Relating an impact indicator with a specific research investment is only valid in the absence of other effects on indicators, such as markets and policies (Ekboir, 2003). In addition, many ROR estimates often fail to account for the effects of work done by others in the research development continuum. Temporal aspects of the attribution problem would result when assuming a specific time lag between research results and their implementation. At times, the period over which research affects productivity may be overestimated. A number of strategies can be used to address attribution, called contribution analysis (Mayne, 1999), which may enhance the validity of the estimates, but do not eliminate the problem.

In many estimates the spill-over effects are not usually included as benefits (see 8.2.7). In others, the effects resulting from changes in rural employment, health and education policies and programs are excluded. Environmental impacts, both negative and positive, are often ignored (see 8.2.5) as well as those costs arising from institutional marketing arrangements. This issue can be addressed through estimations of the ROR for research and complementary services, as well as research. Increasingly it is likely that valuation of nonmarket impacts of agricultural AKST will be incorporated into economic analysis. Past studies did not address these issues because of measurement difficulties and the fact that research impacts directly observable in commodity and factor markets were abundantly available. Research systems are now increasingly called upon to provide positive nonmarket environmental or health benefits as well as to mitigate past negative impacts. A number of economic tools are now available to measure nonmarket environmental benefits and costs such as environmental quality, longevity, and health effects (Freeman, 1985; Feather et al., 1999; Dolan, 2000; Hurley, 2000).

There has been little empirical work in the area of assessing the ROR for social science research, and organizational and institutional innovations including capacity strengthening. This lack is associated with the difficulty of attributing any change in policy, institutions or process and the linked economic growth or poverty reduction to research information generated by social science or other factors (Alston and Pardey, 2001). Attempts to quantify the ROR to social science research have used esoteric methods, utilizing ‘incredible identifying assumptions’ that cannot be robustly defended (Gardner, 2003; Schimmelpfenning and Norton, 2003; Schimmelpfennig et al., 2006). In addition, social and applied science research is often undertaken jointly and difficult to isolate.

8.2.4. Empirical evidence

There are many studies on the ROR of investment in agricultural development. This critique draws heavily upon a number of meta-analyses (Alston et al., 2000a; Evenson, 2001; Evenson and Rosegrant, 2003; Thirtle et al., 2003), which cover 80% of published materials (more than one thousand studies). Most of these studies are associated with production technologies, far fewer address other research outputs e.g. post harvest processing, marketing, policy, organizational or institutional innovations. We recognize the shortcomings in these data but these reviews provide useful insights into impacts of AKST investments across continents, commodities and components (research, extension, private sector research.

8.2.4.1. Rate of returns to national AKST investments

One meta-analysis estimated the economic impact of agricultural R&D investment at the national level for 48 selected developing countries in Africa, Asia, and Latin America (Thirtle et al., 2001) The analysis revealed that R&D expenditures per unit of land have an elasticity of 0.44 in terms of productivity. It was also noted that the elasticity of agricultural R&D is positive and highly significant in all cases and is slightly larger for Africa than Asia and both are over 50% greater than the Latin America’s elasticity. The elasticity of value added per unit of land with respect to agricultural R&D was used to calculate ROR to agricultural R&D at the country and the continental level (Table 8.7). The estimated ROR for the sample countries in Africa ranged between -12 and 58%. In only three cases the gains were less than the expenditures. For the Asian countries, the estimated ROR ranged between -1 and 50%; and appears to be less varied and generally higher. The mean of the country RORs for Asia (26%) is better than for Africa (18%) and the weighted mean (31%) is still higher. These means are dominated by the huge agricultural sectors of China and India, both of which seem to have done well in economic terms. In the case of Latin America, only five of the thirteen countries had positive RORs. The estimated

ROR ranged between -22 and 40%. The poor results for the Latin American countries are at least partly due to the limitation of data availability (Thirtle et al., 2001).

[Table 8.7]

8.2.4.2. Rates of return to crop genetic improvement investments

Over the years, a significant amount of AKST resources have been devoted to genetic improvement. A second assessment of economic consequences of crop genetic improvement estimated the economic impact of 17 commodities and 35 country/regions using a “global market equilibrium” model (Evenson and Rosegrant, 2003). Benefit/cost ratio (using 6% as the external interest rate) and IRRs of crop genetic improvement programs by region have been computed for both national agricultural research systems (NARS) and international agricultural research centers (IARCs) (Table 8.8). The IRRs for the NARS ranged between 9 and 31%, which are considerably lower than the ones reported in individual studies. This is primarily because most individual studies tend to ignore the research costs to build the germplasm stock that is required to reach the stage where benefits are produced. The lowest IRR was observed for SSA (9%). The IRRs for the IARC programs are very high and ranged between 39 and 165%. The lowest IRR was observed for Latin America. These high RORs reflect the leveraging associated with the high production of IARC crosses and high volume of IARC germplasm (Evenson and Rosegrant, 2003).

[Table 8.8]

8.2.4.3. Economic impacts of research and extension investments

A number of economic impact studies were assessed to evaluate the contribution of agricultural research and extension programs both public and private, using the estimated ROR on investment to index economic impacts (Evenson, 2001) (Table 8.9). The benefit exceeded cost in SSA almost 15 years later than was the case for Latin America and Asia, causing the low IRR. The available evidence suggests that the economic RORs to agricultural R&D are high (Evenson, 2001). The broad scope of the evidence for high returns suggests considerable international spillovers. Economic RORs to agricultural research are likely to be above most public and private rates (Fuglie et al., 1996; Alston et al., 2000a; Evenson, 2001). Recently studies have been carried out on the impact of natural resource management research. In most cases however these were satisfactory but lower than in germplasm improvement research (Waibel and Zilberman, 2007).

[Table 8.9]

Due to a variety of market failures, private returns to R&D are far smaller than economic returns as private developers cannot appropriate many of the benefits associated with their research (Evenson and Westphal, 1995; Scotchmer, 1999; Shavall and van Ypserle, 2001) (see 8.1.2). In agriculture in particular, firms often have difficulty in capturing much of the economic benefits of their investments (Huffman and Evenson, 1993); e.g., in the US seed companies retained 30 to 50% of the economic benefits from enhanced hybrid seed yields and 10% of benefits from non-hybrid seed during 1975-1990 (Fuglie et al., 1996). A key market failure that inhibits developers from recovering the cost of R&D in agriculture is the potential for resale of seeds (Kremer and Zwane, 2005). The gap between social and private returns may be more acute in tropical agriculture, where market failures are particularly severe and the intellectual property rights (IPR) environment is weaker (Pray and Umali-Deininger 1998; Kremer and Zwane, 2005).

Very often the reported higher economic ROR is attributed to the selectivity bias. First, highly successful programs are likely to be evaluated. Second, the unsuccessful evaluations are less likely to be published than evaluations showing impact However, one can compare the studies covering aggregate programs, which includes both successful and unsuccessful) with studies of specific commodity programs and the evidence is based on a substantial part the world’s agricultural research and extension programs (Evenson, 2001). A comparative analysis of returns to AKST investments across continents, commodities, types of research, methods of estimation, public versus private, and over time (Alston et al., 2000a) is presented in Table 8.10 - 8.12.

[Table 8.10]

The distribution of ROR for crops, livestock, and multiple commodities is similar to that for the entire sample (Table 8.11). A substantial difference in the distribution of ROR is observed for resources research; these estimates mostly include forestry research, for which the research lags are relatively long, contributing to the relatively low average rates of return. The highest ROR observed for all agriculture, field crops, livestock, tree crops, resources and forestry were 1,219; 1,720; 5,645; 1,736; 457; and 457, respectively. All studies related to livestock and trees had a positive ROR. The mean ROR for livestock R&D was around 121. These data demonstrate that the estimated RORs for livestock species are comparable to the rates estimated for the other sectors. In addition, in this study the overall estimated ROR for animal research was 18% but when this was decomposed, the ROR for animal health research and animal improvement research were found to be 15 and 27%, respectively; indicating the underestimation of ROR for the overall investment. Probably, the decomposition by species would also show different RORs associated to each of them.

[Table 8.11]

Although the mean ROR estimates for industrialized countries is higher than that for developing countries (98 and 60%, respectively), the median are virtually identical (46 versus 43%) (Table 8.12). While there are not many studies from Africa assessing the returns to R&D, the existing analyses generally indicate high returns in the range of 4 to 100% for country level studies (Anandajayasekeram and Rukuni, 1999).

[Table 8.12]

The key findings of the last meta-analysis were (Alston et al., 2000a):

- Research has much higher ROR than extension only or both research and extension combined;
- There is no measurable difference in estimated ROR between privately and publicly performed research;
- The RORs were 25% per year higher for research on field crops and 95% per year lower for research on natural resources than for total agriculture;
- There is no significant difference in rates of return related to whether studies reported basic or other categories of research;
- The estimate also indicates that if research took place in an industrialized country, the ROR was higher by 13% per year, but this effect was not statistically significant at the 10% level. The estimated rates of return tended to be lower in Africa and West Asia and North Africa than in Latin America and the Caribbean or Asia;
- There is no evidence that the ROR to agricultural R&D has declined over time;
- Unable to detect any effect of accounting for spillovers or market distortions on measured rates of return to research.

8.2.4.4. Agricultural research and education investments and agricultural growth

A summary of studies that have applied decomposition analysis to agricultural growth in developing countries suggests that past investments in agricultural research may have contributed anywhere from 5 to 65% of agricultural growth, depending on the country and time period (Pingali and Heisey, 2001). Decomposition of recent measurements of African agricultural growth suggests that up to one-third of the growth in aggregate agricultural productivity is attributable to past investments in agricultural research (Oehmke et al., 1997). This roughly corresponds to a contribution of agricultural research to economic growth of ¼ of a percentage point.

A study on agriculture growth and productivity in the United States demonstrated similar results (Shane et al., 1998). During 1974-1991 annual growth rate of agriculture productivity was estimated to be 2.2% and entire economy productivity growth was 0.2% in the U.S. total factor productivity (TFP) growth rate was 2.3% during 1959-91. During 1949-91, productivity growth in agriculture can be attributed to four major factors: public investment in agricultural R&D (50%), public expenditure on infrastructure (25%), private investment in R&D, and technological advances embodied in material inputs such as fertilizers and chemicals (combined 25%).

Technological advancements depend on the quality and quantity of scientific capacity of the national institutes (Mashelkar, 2005). There is a positive relationship between science enrolment and technology achievement indices indicating that increased investment in human capacity can result in better technological advancement. This relationship has not been fully understood or analyzed in the development literature. In general, there is a lack of analysis or questioning of the role of increased capacity in explaining growth performance in developing counties (Ul Hague and Khan, 1997).

Detailed evidence on the ROR of investments in agricultural education is very limited, but a number of studies have showed that education has a positive impact on economic growth and positive benefits to health and other noneconomic benefits (OECD 2003; Evenson, 2004; Johanson and Saint, 2007). Economic growth increases 4% for every additional year of schooling of the adult population; particularly high attainment levels in secondary and tertiary education are relatively more important for economic growth (UNESCO/OECD 2003). The available evidence on the impacts of tertiary education on economic growth and poverty reduction in the case of SSA Africa show that an increase of one year of tertiary education will result in growth increase of 6% in the first year, and about 3% after five years (Bloom et al., 2007). Another study found that an increase in the number of degrees awarded in natural sciences and engineering in East Asia have a strong positive relationship on GDP per capital levels (Yusuf and Nabeshima, 2007). The expected rates of return to investments in education at primary, secondary and higher level for selected countries in Africa range from 24% for primary education, 18.2% for secondary to 11.4% for higher education (Psacharopoulos, 1994).

Per capita income levels are higher among counties that have invested in educating their population (Babu and Sengupta, 2006) and increased capacity will result in better implementation of programs and policies that reduce poverty and hunger (Kaufman et. al., 2003). Whereas there is a positive relationship between increased capacity and better governance, there is a need for better understanding of the nature and magnitude of the capacity needed to increase governance of development programs and policies that translate the development goals into development outcomes (Babu and Sengupta, 2006).

There is ample evidence available from the literature that AKST investments have contributed significantly to organizational and institutional innovations in the form of methods, tools development, capacity strengthening, and understanding how institutes interact with each other in achieving developmental goals. However, not much work has been done on assessing the RORs on investments in agricultural training and capacity strengthening. Assessing the economic impacts of non-research products such as training, networking and advisory services policy and institutional reforms need greater emphasis. Detailed analysis of causality of agricultural education and capacity strengthening on development outcomes will require identifying indicators that reflect institutional and human capacity to contribute better development processes.

8.2.4.5. Rates of return to CGIAR investments

The CGIAR Science Council's Standing Panel on Impact Assessment (SPIA) commissioned an independent study to weigh the measurable benefits of CGIAR research against the total cost of system operation to 2001 (Raitzer, 2003). The analysis found that the value of documented benefits generated by the CGIAR surpasses total investment in the system. The analysts did not calculate a single benefit-cost ratio for all potential audiences. Instead, they offered five different versions of the benefit-cost ratio to allow for its sensitivity to different assumptions regarding the credibility of the values derived for key measures of benefit. The most restrictive assessment yields a benefit cost ratio of 1.9, i.e., returns of nearly 2 dollars for every dollar invested. The most inclusive estimate puts the benefits–cost ratio nearly nine times higher.

The analysis excluded the benefits from the vast majority of CGIAR work, which has not been subject to large-scale ex-post economic assessment. The analysis aggregated only published large-scale economic assessments that met a strict set of criteria for plausibility and demonstration of causality. As a result, only a few isolated examples of success are used to produce these substantial benefit levels, and many probable impacts that lack reliable quantification are omitted. To underscore this point, the economic value of benefits derived from just three CGIAR innovations is estimated to be greater than the entire US $7 billion (in 1990 prices) invested in the IARCs since the CGIAR was established. Under very conservative assumptions, benefits generated (through 2001) from: (i) new, higher yielding rice varieties in Latin America, Asia, and West Africa; (ii) higher-yielding wheat in West Asia, North Africa, South Asia, and Latin America; and (iii) cassava mealybug biocontrol throughout the African continent combined almost twice the aggregate cumulative CGIAR costs. If slightly more generous assumptions were applied, the estimated benefits generated to date by these three technologies rise to more than eight times the total funds invested in CGIAR research and capacity-building programs. If impact assessment were applied to a larger proportion of the system's portfolio than these three innovations will result in much higher aggregate benefit values. Furthermore, the aggregated studies do not take into account multiplier effects that result from stimulated growth in the nonfarm economy, or nonmarket benefits. As a result, even the most generous of the values reported may be considered as conservative (Raitzer, 2003).

8.2.4.6. Rates of return to agricultural R&D investments in sub-Saharan Africa

A compilation of the available case studies on ROR for African agricultural R&D investment support findings of four meta-analyses (Table 8.13). Of the 27 RORs to past investments in agricultural technology development and dissemination (TDT), 21 show RORs in excess of 12%. Detailed investigations into the lower RORs suggest that researchers had not yet found the right mix of activities to produce cost-effective solutions in challenging agroecological environments. Examining the future potential impact of innovations released or still in the development stage, 24 of 30 forward-looking RORs show expected returns in excess of 12%. The second study reviewed the impact studies conducted in Eastern and Southern Africa (ESA) during 1978-2005 (Anandajayasekeram et al., 2007). The RORs for those studies using the noneconometric methods ranged from 0 to 109. For those studies using the econometric methods ranged between 2 to 113%. Only 10 out of the 86 observations were below 12% under the worst case scenario. These compilations confirm that returns to research in SSA are similar to those found elsewhere, showing a high pay off for a wide range of programs.

[Table 8.13]

8.2.5. Environmental impacts of AKST investments

The success of modern agriculture in recent decades has often masked significant externalities that have positively and negatively affected natural resources. Externalities of agriculture include the depletion of resources such as fossil fuel, water, soil and biodiversity; pollution of the environment by the products of fuel combustion, pesticides and fertilizers; and economic and social costs to communities. In the past, the objectives of AKST investments have been largely to increase quality, quantity and to improve food security. Thus, the environmental impacts of agricultural technologies were not usually considered in ROR and other decision-making tools. Their importance, however, is increasingly understood because of the positive link between ecologically sustainable development and poverty reduction (UNEP, 2004a). A good example at the national level is a study that estimates the total external environmental and health costs of 'modern agriculture' in the United Kingdom at a total cost of £2343 million in 1996 (Pretty et al., 2000). This is equivalent to 89% of average net farm income and £208 per hectare of arable and permanent pasture. These estimates only include those externalities that give rise to financial costs, and so are likely to underestimate the total negative impacts to the environment. The quality and size of environmental impacts depend on many external forces. Different agroecological zones, market conditions, and financial and social incentives as well as specific technologies play significant roles in determining impacts. In order to quantify and value the environmental impact of an agricultural R&D investment, it is important to understand the source of the impact, the nature, and the relationship between the impact and those variables that can affect producers and consumers. Agriculture globally (including livestock and land use, but excluding transport of agricultural products) has an estimated contribution to GHG emissions of 32% (Stern, 2006).

Although many economic valuation techniques have been developed and refined over the last twenty years, obtaining monetary values of environmental impacts is difficult due to two basic reasons. First, the issue of time and scale complicates the data collection and valuation. Many of the environmental impacts are accumulative by nature, and thus time is a critical constraint in estimating values. Geographic scale is also critical, for example, captive shrimp production leads to a large-scale pollution of marine environments and destruction of mangroves (Clay, 2004). In general, environmental and ecological economists consider the scale either through an ecosystem-centric lens: the plot, the farm, the watershed, and region (Izac and Swift, 1994) or a human-centric lens: the individual farmer, the local community, downstream communities, national citizens and the global population. These issues of scale are seldom incorporated into ROR calculations or other decision-making tools, and thus they exclude the critical elements of ‘who pays, who benefits’. Second, reconciling different levels of aggregation to obtain reliable estimates is complex. For example, movement of pesticides through soil is determined by several factors such as specific soil characteristics (physical and chemical), properties of the soil, the climate, crop management practices, and so on. The problem is how to generate information that reflects the complex of physical, biological and technical factors. One of the more difficult areas to estimate is the value of impacts on and by biodiversity, because the links between biodiversity and ecosystem functions and services is less understood than many other environmental interactions. Moreover, no monetary values can be given to it and the value is also context-specific and relative to the livelihoods and uses given to biodiversity. The willingness is related to the knowledge of the impacts of biodiversity loss, including the impact of climate change (Turpie, 2003).

New development in economic science, such as ecological economics, can bring promising tools in the future to measure externalities and tackle the problems identified above (Proops, 1989; Jacobs, 1996). One example is the evaluation of hundred years of agricultural production in the

Rolling Pampas of Argentina by analysing energy flows within systems (Ferreyra, 2006). The ecological footprint quantifies the amount of resources required by a production method or a technology related to AKST, and thus, can give an idea of the environmental impact (Wackernagel and Rees, 1997) and was used to assess the resource use and development limitations in shrimp and tilapia aquaculture (Kautsky et al., 1997).

Due to the complexity of agriculture and the links with the food chain, most studies, particularly ecological economic studies, examine the impacts of food systems and not the technologies in isolation. There is a significant paucity of data and studies on environmental impacts (see below as well as Table 8.14).

[Table 8.14]

8.2.5.1. Agriculture

Biodiversity loss. Reduction in the use of biodiversity in agriculture is driven by the increased pressures and demands of urban and rural populations and by the global development paradigm, which favors specialization and intensification (FAO, 2003). Most studies combine influences and impacts from crop and livestock systems. The total economic benefits of biodiversity with special attention to the services that soil biota activities provide worldwide is estimated to be US $1,542 billion per year (FAO et al., 1997; Pimentel et al. 1997). The estimated total damage to UK’s wildlife, habitats, hedgerows and drystone walls was £125 million in 1996 (Pretty et al., 2000).

Soil erosion. Scientists estimate the global cost of soil erosion at more than US $400 billion per year. This includes the cost to farmers as well as indirect damage to waterways, infrastructure, and health (Pimentel et al., 1995). In the UK, the combined cost of soil erosion with organic carbon losses was £106 million in 1996 (Pretty et al., 2000).

Pesticides and chemical fertilizers. Agricultural runoff pollutes ground and surface waters with large amounts of nitrogen and phosphorus from fertilizers, pesticides and agricultural waste. Agriculture is the main cause of pollution in US rivers and contributes to 70% of all water quality problems identified in rivers and streams (Walker et al., 2005). In the UK the cost of contamination of drinking water with pesticides is £120 million per year (Pretty et al., 2000).

Carbon sink. Agricultural systems contribute to CO_2 emissions through several mechanisms: (i) the direct use of fossil fuels in farm operations; (ii) indirect use of fossil fuels through inputs, such as fertilizers; and (iii) the loss of soil organic matter. On the other hand, agricultural systems accumulate carbon when organic matter is accumulated in the soil, or when above-ground woody biomass acts either as a permanent sink or is used as an energy source that substitutes for fossil fuels (Pretty and Ball, 2001). A 23-year ongoing research project by the Rodale Institute in the US found that if 10,000 medium-sized farms in the US converted to organic production, the carbon stored in the soil would equal taking 1.2 million cars off the road, or reducing car travel by 27 billion kilometers (The Rodale Institute, 2003). Forty sustainable agriculture and renewable-resource-management projects in China and India (Pretty et al., 2002) increased carbon sinks in soil organic matter and above-ground biomass; avoided carbon emissions from farms by reducing direct and indirect energy use; and increased renewable energy production from biomass. The potential income from carbon mitigation is \$324 million at \$5 tonne^{-1} of carbon (Pretty et al., 2002).

Water use. Agriculture consumes about 70% of fresh water worldwide. For example, the water required for food and forage crops growing ranges from about 300 to 2,000 liter kg^{-1} dry crop yield, and for beef production 43,000 liter kg^{-1} (Pimentel et al., 2004). Virtual water refers to the water used in the production process of an agricultural product (Chapagain and Hoekstra, 2003). Using a virtual water approach, some countries are net importers of water while others are exporters. It is expected that in the future, approaches to quantify the amount of water used by different countries or regions will be extremely important.

8.2.5.2. Livestock

The livestock sector has enormous impacts on the environment: it is responsible for 18% of GHG emissions measured in CO_2 equivalents, and 9% of anthropogenic CO_2 emissions, including the combustion of fossil fuels to make the additional inputs. Globally, it accounts for about 8% of human water use, mostly for the irrigation of feed crops (Steinfeld et al., 2006). It is estimated that 1 kg of edible beef results in an overall requirement of 20 to 43 tonnes water per kg of meat (Smil et al., 2002; Pimentel et al., 2004). The total area occupied by grazing is equivalent to 26% of the world land; the total agricultural area dedicated to feedcrop production is 33%. In all, livestock production accounts for 70% of agricultural land and 30% of land globally (Steinfeld et al., 2006). It is probably the largest sectoral source of water pollution. In the US, livestock are responsible for 55% of soil erosion and sediment, 37% of pesticide use, 50% of antibiotic use and a third of the loads of nitrogen and phosphorus into freshwater resources (Steinfeld et al., 2006). Data are not available to estimate these impacts from an economic perspective. ‘Emergy’ evaluations have recently been used to evaluate the costs of grazing cattle in Argentina’s Pampas (Rótolo et al., 2007); to compare soy production systems in Brazil (Ortega et al., 2003); and to compare organic and conventional production systems (Castellini et al., 2006).

The rapid spread of large-scale industrial livestock production focused on a narrow range of breeds is the biggest threat to the world's farm animal diversity (FAO, 2007). Traditional livestock losses worldwide range from one breed per week (Thrupp, 1998) to one per month (FAO, 2007). Many traditional breeds have disappeared as farmers focus on new breeds of cattle, pigs, sheep, and chickens. In the year 2000, over 6,300 breeds of domesticated livestock were identified; of these, over 1,300 are now extinct or considered to be in danger of extinction. Many others have not been formally identified and may disappear before they are recorded or widely known. When breeds without recorded population data are included, the number at risk may be as high as 2,255. Europe records the highest percentage of extinct breeds or breeds at risk (55% for mammalian and 69% for avian breeds). Approximately 80% of the value of livestock in low-input developing-country systems can be attributed to non-market roles, while only 20% is attributable to direct production outputs (FAO, 2007). By contrast, over 90% of the value of livestock in high-input industrialized-country production systems is attributable to the latter. How to measure or evaluate the importance of considering nonmarket values of livestock when planning AKST investment is lacking. Obtaining such data frequently requires the modification of economic techniques for use in conjunction with participatory and rapid rural appraisal methods (FAO, 2007).

8.2.5.3. Forestry

There are different forestry systems ranging from systems of monoculture of trees (aiming to obtain products such as cellulose, wood or other products) to systems that cultivate different tree species with other agricultural products, including livestock. Agroforestry systems (AFS) provide a mix of market and nonmarket goods and services with a high level of output per purchased investments and minimal environmental impacts (Diemont et al., 2006). An agricultural system that includes agroforestry is more profitable than a conventional system (Neupane and Thapa, 2004); agroforestry has great potential to minimize the rate of soil degradation, increase crop yields and food production, and raise farm income in a sustainable manner.

8.2.5.4. Aquaculture

Intensification of aquaculture has resulted in higher impacts into the environment. A deeply analyzed case is that of shrimp farming. In a simple cost-benefit analysis, industrial shrimp farming is usually found to be profitable; however, cost-benefit analyses that include environmental costs, can contradict these findings. For example, a study performed in India concluded that shrimp culture caused more economic harm than good. The economic damage (loss of mangroves, salinization and increasing unemployment) outweighed the benefits by 4 to 1 or 1.5 to 1, depending on the areas considered (Primavera, 1997). In Thailand, the total economic value of an intact mangrove exceeds that of shrimp farming by 70% (Castellini et al., 2006). The estimated internal benefits of developing shrimp farms are higher than the internal costs in the ratio of 1.5 to 1 (Gunawardena and Rowan, 2005). When the wider environmental impacts are more comprehensively evaluated, the external benefits are much lower than the external costs in a ratio that ranges between 1 to 6 and 1 to 11.

In Malawi, the ecological footprint approach applied to integrated aquaculture showed that when waste from each farming enterprise is recycled into other enterprises, the economic and ecological efficiencies of all are increased (Brummet, 1999).

8.2.5.5. Traditional and local knowledge

Traditional knowledge and local farming systems associated are often either ignored or sidelined by new technologies and profit-oriented interventions (Upreti and Upreti, 2002). Though there is no economic valuation estimated in monetary terms, it is well recognized that there is tremendous value in traditional knowledge for maintaining and improving farming systems, particularly with regard to agrobiodiversity management and utilization.

In recent years researchers have started to address this significant gap. For example, a new conceptual framework was developed to assess the value of pastoralism that goes beyond conventional economic criteria (Hesse and McGregor, 2006). The objective is to provide fresh insights to its contribution to poverty reduction, sustainable environmental management and the economically sustainable development of dryland areas of East Africa in the context of increasing climate uncertainty. One can associate environmental impacts of pastoralist traditional knowledge in terms of sustainable land use and risk management in disequilibrium environments, biodiversity conservation and improved agricultural returns, but these too are rarely captured in national statistics or recognized by policy makers.

8.2.6. Health impacts of agricultural R&D investments

The interactions between agriculture and human health are well recognized. Agricultural technologies through their effects on productivity, income, and food quality and security can improve the health status of producers and consumers (Table 8.15); healthier people will generally be more productive than people who suffer from sickness or who are undernourished. On the other hand, agricultural technologies can have negative effects on the health status of farmers, farm laborers, farm household members and consumers (Table 8.16).

Pesticides are an example of positive (increases in productivity), and negative (environment and human health) effects (see also 8.2.5). There are at least 1 million cases of pesticide poisoning annually, with women and children in developing countries disproportionably affected (WHO, 1990; UNEP, 2004b). The total number of unintentional fatal poisonings from all sources, including agricultural chemicals, is 350,000 per year (WHO, 2006). These global figures are not collected systematically or on a regular basis; estimation of the incidence of pesticide poisoning is difficult as surveillance systems may be inadequate and tend to underreport (PAHO, 2002; London and Bailie, 2001). Hence, official reports represent lower bound estimates. Farmers in the developing world experience high rates of exposure to human health risks when using pesticides (Jeyaratnam et al., 1982 and 1987; Kishi et al., 1995; Ajayi, 2000; Rola and Pingali, 1993; Antle et al., 1998; Crissman et al., 1994 and 1998). Some authors (Cuyno et al., 2001; Garming and Waibel, 2006) established that farmers reveal a willingness to pay for reducing the negative health effects from chemical pesticides.

Economic studies carried out in industrialized countries found that health costs make up about 10% of the total externality costs of pesticides (Pimentel et al., 1993ab; Waibel et al., 1999). Pesticide use globally continues to rise and hence the concerns about the implications for human health remain (Ecobichon, 2001).

Considerable AKST investments were made by the public and the private sector to minimize the negative health effects of pesticides. These investments included two major products, safe use technology packages and IPM. Chemical companies have developed modules on safe use training, which is an example of a private sector AKST. Pilot projects were carried out in Mexico, India and Zimbabwe (Atkin and Leisinger, 2000), Guatemala, Kenya and Thailand (Hurst, 1999). Successes were very limited; Farmers often went back to their old practices shortly after the training (Atkin and Leisinger, 2000). In addition, some safe use technologies (e.g., protective equipment) and management practices, (e.g., hygienic measures after spraying, compliance with re-entry intervals, safe storage of equipment and pesticides) were often found unfeasible in tropical climates and under the conditions of poor countries (Cole et al., 2000).

A good of example of public sector AKST investment to mitigate the negative impact of pesticide use is IPM; IPM technologies are site-specific in that they need to be developed for specific agroecological, socioeconomic and policy conditions. As a result a wide range of examples exist in both developing and industrialized countries. Despite the large amount of investment in IPM, global impact studies are rare. A meta-analysis for the CGIAR in 1999 showed that, although no aggregate ROR could be established, the ROR for IPM was above 30%, and this does not include the significant environmental and health benefits. In the industrialized countries several successful IPM programs have been implemented in selected crops (e.g. Norton, 2005), but successes on the aggregate level remain questionable due to a lack of enabling policy conditions (Waibel et al., 1999).

Iron, zinc and iodine deficiencies are widespread nutritional imbalances (WHO, 2002; FAO, 2004; Hotz and Brown, 2004; UN-SCN, 2004). The adverse health outcomes of micronutrient deficiencies include child and maternal mortality, impaired physical and mental activity, diarrhea, pneumonia, stunting or blindness, among others (Stein et al., 2005). Biofortification research aims to reduce malnutrition by breeding essential micronutrients into staple crops. The CGIAR HarvestPlus Challenge Program concentrates on increasing iron, zinc and beta-carotene (provitamin A) content in six staple crops species (rice, wheat, maize, cassava, sweet potatoes and beans). In addition, the program supports exploratory research in ten additional crops (Qaim et al., 2006). Most biofortified crops are in R&D phase, except for beta-carotene rich orange fleshed sweet potatoes and Golden Rice (Low et al., 1997; Goto et al., 1999; Ye et al., 2000; Lucca et al., 2001; Murray-Kolb et al., 2002; Asconcelos et al., 2003; Drakakai et al., 2005, Ducreux et al., 2005).

Thus far, only ex-ante economic analyses exist for biofortified crops. An evaluation of the potential health benefits of Golden Rice in the Philippines showed that micronutrient deficiencies can lead to significant health costs, which could be reduced through biofortification (Zimmermann and Qaim, 2004). In an ex-ante impact assessment using disability adjusted life years (DALYS) approach (Qaim et al., 2006) the estimated Internal Rate of Return (IRR) was very high, ranging 31 to 66% (pessimistic scenario) and 70 to 168% (optimistic scenario). Ex-ante studies on the expected impact of biofortification research under HarvestPlus have been conducted for rice in the Philippines, beans in Brazil and Honduras, sweet potato in Uganda, maize in Kenya and cassava in Nigeria and Brazil; health-cost reductions range from 3 to 38% in the pessimistic scenario and from 11 to 64% in the optimistic scenario depending on crop and location (Meenakshi et al., 2006).

To find out if biofortified crops will be adopted by growers on a large scale requires research including ex-post studies building on observable data to verify the preliminary results. Further research is also needed on the bioavailability and micronutrient interactions in the human body. The key conclusion emerging from the available ex- ante studies is that biofortification could play an important role in achieving nutrient security in particular situations. However, its benefits will depend on the necessary institutional framework that can facilitate the effective introduction of these technologies as well as an enabling policy framework.

Other impacts of AKST on health, both positive and negative, can be shown with the development of industrial livestock. Livestock products contribute to improved nutrition globally and are linked to disease, such as cardio-vascular disease, diabetes and certain types of cancer (Walter et al., 2005).

8.2.7. Spillover effects

The wide applicability of research results over a range of agricultural production conditions or environments often cutting across geographical and national boundaries are generally referred to as spillover effects. Spillover effects are a combination of four effects: price effects from the increased production caused by reduced costs which are captured in the supply and demand framework (Hesse and McGregor, 2006). Spill-over technology from country “Y” which can be adopted without any research in country “X”; spillover of technology from country “Y” which requires adaptive research before it is applicable in country “X”; and spillover of scientific knowledge which ultimately enhances future research in many areas.

Technological spillovers increase the returns to research and can be spill-ins or spill-outs. Spill-ins take place when a country is adapting a technology developed elsewhere. This reduces the national research costs and shortens the time required for developing and disseminating the finished product. The gains from spill-ins are important to all research organizations, but are higher in smaller systems. Spill-outs take place when research findings are used by other countries. Spill-outs are important when one is interested in the total benefits occurring to the country where the technology was developed as well as the country where it was adopted. This aspect is critical when performing impact assessment of a regional network (Anandajayasekeram et al., 2007).

It has been long recognized that AKST spillovers are both prevalent and important (Evenson, 1989; Griliches, 1992). A study that fails to account appropriately for spill-ins will overestimates the benefits from its own research investment.[7] Similarly if state to state or nation to nation spillovers are important—as in the case of regional research networks- and the study measures its own benefit at the national level and ignores the “spill-outs”, this will underestimate the ROR. Only 12% of the 292 studies in the sample of one of the aforementioned meta analysis made any allowance for technology spillovers; even fewer allowed for international spillovers (Alston et al., 2000a). They also noted that by far the majority of research impact studies that have allowed for international agricultural technology spillovers were commodity specific studies, rather than national aggregate studies, and mostly they were studies of crop varietal improvements.

A study covering twelve different commodities and using a multi-country trade model, found that spillover effects from regions where research is conducted to over regions with similar

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[7] Farmer to farmer spill in / outs are also important, not just locally but where they happen through travel, guest worker return etc, but not easy to capture.

agroecologies and rural infrastructures ranged from 64 to 82% of total international benefits (Davis et al., 1987). An analysis of 69 national and international wheat improvement research programs found that ‘given the magnitude of potential spill-ins from the international research system, many wheat programs could significantly increase the efficiency of resource use by reducing the size of their wheat research programs and focusing on the screening of varieties developed elsewhere (Davis et al., 1987). The impact of research conducted within individual Latin American and Caribbean countries covering edible beans, cassava, maize, potatoes, rice, sorghum, soybeans and wheat showed that when allowance was made for spillovers to other regions of the world, the resulting price impacts had important consequences for the distribution of benefits between producer and consumers and thus among countries within Latin America and the Caribbean (Alston et al., 2000b). At least for the United States, the locational range of spill-in effects for crop production is lower than for livestock production (Evenson, 1989). Crop genetic improvements in the United States had spillover effects into the rest of the world, with consumers in the rest of the world gaining but producers outside the United States losing (Frisvold et al., 2003). Overall increases in net global welfare from United States crop improvements were distributed 60% to the US, 25% to other industrialized countries, and the remainder to developing and transitional economies.

Growth in public funding for international research has slowed over the last twenty years (see 9.1). Thus, understanding the ROR of the CGIAR is very important, including the spill in and spill out impacts. Over the years, a number of studies have attempted to value the benefits to particular countries from research conducted at CG centers, in some cases comparing them against donor support provided by the countries in question (Brennan, 1986, 1989; Burnett et al., 1990; Byerlee and Moya, 1993; Bofu et al., 1996; Fonseca et al., 1996; Pardey et al., 1996; Brennan and Bantilan, 1999; Johnson and Pachico, 2000; Brennan et al., 2002; Heisey et al., 2002). For the period 1973-1984, Australia gained US $747 million in terms of cost savings to wheat producers as a United States benefit from its adoption of wheat varieties from CIMMYT and rice varieties from IRRI (Brennan, 1986, 1989). Depending on the attribution rule used, the United States’ economy gained at least US $3.4 billion and up to US $14.6 billion from 1970 to 1993 from the use of improved wheat varieties developed by CIMMYT and US $30 million and up to US $1 billion through the use of rice varieties developed by IRRI.[8] These estimates did not account for the world price impact as a result of the rest of the world having adopted CIMMYT wheat varieties and thereby driving down the price of wheat.

Assessments were made of Australia’s benefits from research conducted by ICRISAT and ICARDA taking explicit account of the world price impacts (Brennan and Bantilan, 1999; Brennan

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[8] For a discussion of the issues related to these estimate see Alston (2002) and Pardey et al. (2002).

et al., 2002). Research on sorghum (ICRISAT) resulted in a national benefit of US $3.6 million (producer loss of US $1.7 million and consumer gain of US $5.3 million) for Australia. Similarly, ICRISAT's research on chickpeas would have given a national benefit of US $1.2 million (producer loss of US $2.6 million and a consumer gain of US $3.8 million). The average estimated net gain to Australia as a result of the overall research effort at ICARDA in five crops (durum wheat, barley, chick pea, lentils and faba bean) is US $7.4 million per year (in 2001 dollars and exchange rates) over the period to 2002 (Brennan et al., 2002). This represents 1% of the gross value of Australia's production of the five crops. Most of those gains are achieved in the faba bean and lentil industries. Producers receive most of the welfare gains in Australia, amounting to US $6.5 million of the total.

The main findings of the various studies are (Alston, 2002):

- Intra national and international spillovers of public agricultural AKST results are very important.
- Spillovers can have profound implications for the distribution of benefits from research between consumers and producers and thus among countries, depending on their trade status and capacity to adopt the technology.
- It is not easy to measure these impacts, and the results can be sensitive to the specifics of the approach taken, but studies that ignore spillovers are likely to obtain seriously distorted estimates of ROR.
- Because spillovers are so important, research resources have been misallocated both within and among nations.

The estimation of these state, national or multinational impacts is data intensive, difficult, and adds to the measurement problems (Alston, 2002). However, there can be little doubt that agricultural AKST generates very large benefits and that a very large share of those benefits comes through spillovers. The omission or mis-measurement of spillover effects may have contributed to a tendency to overestimate ROR to agricultural AKST in some instances. Clearly, the issue of international research spillovers is an important one for the allocation of resources for research both nationally and internationally. The spillover benefits to industrialized countries from international agricultural research have positive funding implications. More work is needed in this area to develop better methods to measure spillovers and also to develop the necessary policy institutional arrangements to harness the full potential of spillover effects of AKST technologies (Alston, 2002; Anandajayasekeram et al., 2007).

Agricultural machinery and agricultural chemicals are obvious cases where industrial AKST is directed towards the improvement of agricultural inputs. Recent studies conclude that when new industrial products first come on the market, they are priced to only partially capture the real value of the improvement (most new models of equipment are better buys than the equipment that they replace) (Evenson, 2001). This produces a spill-in impact. Another type of spill-in that is recognized in few studies is the “recharge” spill-in from pre-invention science. Many of the studies summarized in the meta-analysis actually covered a wide range of research program activities including many pre-invention science activities. Some studies specifically identified pre-invention expenditures and activities as well as industrial spill-ins (Table 8.17). These studies report relatively high rates of return and are roughly equal to the social RORs to public agricultural research.

[Table 8.17]

8.2.8 Impacts of public sector agricultural R&D investments on poverty

Several recent studies (Fan et al., 2000; 2004ab, 2005; Fan and Zhang, 2004) clearly indicate that public investment in agricultural R&D is the most efficient public sector investment (with the exception of Ethiopia). In terms of number of poor people moving out of poverty, agricultural R&D investments ranked among the top three. Although limited, this evidence indicates that the investment in agricultural R&D performs equally as well or better than the other public sector investments and contributes significantly to poverty reduction. These studies measured the effects of public spending on growth and poverty reduction in selected Asian and African countries using pooled time-series and cross-region data (Table 8.19).To assess the impact of public investment on poverty, the number of poor people who would come out of poverty for a fixed investment across different sectors was estimated. Similar to estimate the economic benefit of the investment the benefit/cost ratios were estimated at the national level based on the increase in household income and/or productivity per unit of investment. In Asian countries, the growth effects of investments in agricultural research, roads and education are found to be large. Regional differences were observed within the countries. This demonstrates that there is an opportunity to improve the growth and poverty impacts of total public investments through better regional targeting of specific types of investment (Fan et al., 2005).

Effects of improved technology on income distribution across farms with different resource endowments have been ambiguous. Poverty reduction is largely about distribution. The benefits of agricultural research investments are large and undisputed, but their actual levels and distributional effects remain under discussion (Alston and Pardey, 2001). Measurement of distributional effects can, in principle, be made using economic surplus methods (Alston et al., 1995), although such measurement is not common. One reason why the debates continue may be that discussions of research impacts on poverty implicitly refer to only one of two separate concepts, absolute and relative poverty. Absolute poverty is a measure of how many people lie below a certain income threshold; relative poverty measures the degree of income inequality.

Studies that show positive effects of agricultural R&D on poverty alleviation may implicitly be considering absolute poverty; studies that indicate negative effects may be more likely to refer to relative poverty (Foster, 1998).

[Table 8.18]

There are three sets of factors which further conflate attempts to analyze the impact of AKST on poverty reduction. First, what is the role of underlying socioeconomic conditions in determining the benefits/costs of AKST? It is easy to find cases in which poor farmers with small land holdings have benefited as much as large-scale farmers, and those in which the benefits of new technology were confined to wealthy, more commercialized farms only. Which outcome predominates depends primarily on the underlying socioeconomic conditions of a particular case rather than the characteristics of the technology per se (Kerr and Kolavalli, 1999). Second, what is the role of the underlying social and political institutions? A review of the impacts of agricultural research on the poor (Kerr and Kolavalli, 1999) shows that it is difficult to make generalizations about the impacts of agricultural research on the poor and the distribution of benefits depends on the underlying social and political institutions rather than technology per se. Effects of improved technology on income distribution across farms with different resource endowments have been ambiguous. About 80% of a review of 324 papers on the distributional impacts of the green revolution argued that inequity worsened, but there were significant variations within the data set (Freebairn, 1995). Innovations in agricultural research will not reduce poverty in the absence of poverty-focused policy and action (Gunasena, 2003). Third, in the absence of specific data on the impacts of AKST on poverty alleviation, one can not simply use economic growth nor yield increases as a proxy for poverty reduction. The effect of agricultural research on poverty is usually linked in the literature through its effects on agricultural productivity (Kerr and Kolavalli, 1999). However, increasing productivity is not enough to decrease poverty (Palmer-Jones and Sen, 2006). There are other factors that can affect poverty which are not affected by the increase in productivity, such as the distribution of the income, the adoption of the technology or the suitability of the technology for the rural community. In addition, increased food supply does not automatically mean increased food security for all. What is important is who produces the food, who has access to the technology and knowledge to produce it, and who has the purchasing power to acquire it (Pretty and Hine, 2001). Sub-Saharan Africa has experienced growth in the agricultural sector (FAO, 2005b); additional analysis is needed to understand who has benefited from this growth, and why this growth did not translate into increased food security.

There is no agreement in the literature as to what kind of technologies would have the biggest impact on the reduction of hunger and poverty. While some authors agree that the main problem is not the technology itself, but the access of the poor to new technologies, others would argue that the problem is that the technologies developed are not pro-poor, and benefit only the wealthier farmers. Often, poor farmers do not have access to the technologies and do not participate in the decision process on technologies. Thus, the research process ignores farmers' knowledge and experience even though they may offer insights that could help identify and/or develop effective technologies for unfavorable areas. For that reason the technologies developed may increase productivity but this may not be their main objective. Such systems may perpetuate a sense of helplessness among resource-poor farmers as they wait for effective technological solutions. Recently, some explicit efforts are being made to include farmers' needs in the R&D agenda. All actors seem to agree that participatory approaches are needed; participatory plant breeding seems to be promising (Almekinders and Eling, 2001). What remains unclear is what role the industry would play in this democratization process.

The poverty reduction effect can be substantial and it is free, in the sense that R&D has already paid for itself, whereas redistribution can be counterproductive due to its negative effects on growth (Thirtle et al., 2003). A long-run view of technological change must take into account the distributional effects of agricultural research investments. These research investments go beyond technology and include institutional innovations and the structure of the innovation system catering to agriculture. The distributional impact of technological change ultimately depends on the particular context of policies, markets, and institutions and on interregional connectedness through infrastructure (von Braun, 2003) (Figure 9.8). Adoption of technologies and success depends on many factors, e.g., land ownership, access to water, and availability and efficient use of diverse plant genetic resources (von Braun, 2003). This is in line with the argument that at the farm level, prices, access to inputs and resources, credit and markets, education levels and the distribution of land, affect both the rate of uptake of improved technologies and the extent to which they benefit the poor (Hazell, 1999). Improved technologies may fail to benefit poor farmers not because they are inherently biased against the poor, but because the distribution of land, or access to resources and markets is inequitable. When these are taken into account it becomes possible to explain why similar technologies can have very different impacts on the poor in different regions, or at different times.

[Insert Figure 8.8]

Research needs to focus on commodities used by poor people, and on areas where the poor are concentrated (rain fed highlands, semiarid tropics and marginal lands) (Gunasena, 2003). Without adequate investment in infrastructure, technology and human development in these areas conditions are likely to deteriorate further. Technologies likely to succeed in these areas include mixed farming systems; livestock and agroforestry, improved fallows, and cover crops (Gunasena, 2003). In all cases marketing institutions need to be developed to support the small-scale farmers.

Although less controversial than biotechnology, low-external-input agriculture (LEIA) is also the subject of considerable disagreement (DIFD, 2004). Debate on the relevance of these technologies is unfortunately often clouded by ideology. A dataset containing information on 208 cases from 52 developing countries show that in these projects and initiatives, about 9 million farmers have adopted sustainable agriculture practices and technologies on 29 million hectares (Pretty and Hine, 2001). This demonstrates that sustainable agriculture can reduce food poverty through (i) appropriate technology adapted by farmers' experimentation; (ii) a social learning and participatory approach between projects and farmers; (iii) good linkages between projects/initiatives and external agencies, together with the existence of working partnerships between agencies; (iv) presence of social capital at local level. A variety of options are available to increase the returns to families from their production, either by reducing losses to pests (better storage and treatment) and inefficient processes (e.g., fuel-saving stoves); or by adding value before sale or use (conversion of primary products through processing). Adding value through direct or organized marketing may involve improvements to physical infrastructure (e.g., roads, transport); or through direct marketing and sales to consumers (thus cutting out wholesalers and "middlemen").

Other aspects that need attention are the effects of the crop technology adoption on gender, for example, in the distribution of work roles in the cropping (Von Braun and Webb, 1989) and the significant spatial dependence on growth rates of agricultural output (Palmer-Jones and Sen, 2006).

Additional important issues to be considered in terms of effects of AKST on poverty reduction include (i) how researchers are evaluated (Gunasena, 2003); (ii) poverty alleviation as specific target in agricultural policy (Gunasena, 2003); (iii) relationship of increased productivity to reduced food prices, and evidence that rural poverty is linked to international world prices (Minota and Daniels, 2005; Yavapolku et al., 2006). In addition, indebted countries may have economic growth but not poverty reduction as they must pay a substantial part of GDP to external debt. The future is not just about the need for more scientific effort and technical breakthroughs generated by both more public funding and private sector interventions, but about the political economy of agriculture and food in the developing world (Scoones, 2003). Two basic components of well-being are having a secure livelihood to meet one's basic needs, and realizing and expanding one's capabilities in order to achieve fulfillment. For that reason measuring the link between poverty and agricultural growth by using the human development index or developing new indexes may be necessary.

8.3 Governance of AKST investments: towards a conceptual framework

8.3.1. Demand for improved governance

Particularly since the mid-1980s, there has been increasing demand for AKST systems to be accountable to various stakeholders. These demands have been prompted by the high transaction costs of conventional agricultural research systems in knowledge generation and transfer as well as inefficiency in resource allocation and utilization (Von Oppen et al., 2000). Other reasons for recent demands include lack of transparency, exclusion of other stakeholders from the process of setting research agendas, unequal access to technologies emanating from research and fear of private sector monopoly over technologies, particularly in biotechnology (McMahon, 1992; Reisfschneider et al., 1997; Echeverria, 1998; Von Oppen et al., 2000).

The pressure for accountability is varied across countries and regions. For example, in industrialized countries issues of efficiency and pluralism in the research process are becoming more important (Heemskerk and Wennink, 2005). In most Asian and Latin American countries, the pressure for more accountability seems to be driven by local stakeholders (Byerlee and Alex, 1998; Von Oppen et al., 2000; Hartwich and Von Oppen, 2000). In the case of sub-Saharan Africa, it is the donors, who provide more than one-half of the funding for agricultural research in some countries (see 8.1), who pressure for accountability (Herz, 1996). These demands for accountability have resulted in changes in both the sources and the mechanisms for funding AKST (8.1.4) and hence the rules and modalities which govern the mobilization and utilization of AKST investments.

8.3.2 Defining and judging governance in relation to AKST investments

The changes in governance of AKST can be viewed as part of an `induced institutional innovation' (Ruttan, 2003), which sees changes in institutions or governance driven by factors of demand and supply. On the demand side, the contemporary economic and social realities (including developments of new technologies) are pushing for changes in governance and institutions mediating AKST investments globally, nationally and at lower levels within nations. On the supply side, advances in social science knowledge are increasingly an important source of shifts in the supply of institutional solutions (Ruttan, 2003). Thus the accumulated knowledge (both theoretical and empirical) on the functioning of institutions can be viewed as facilitating the supply of new institutional solutions.

The discussion of governance and the criteria to judge good governance can be approached in several ways. These criteria can be based on certain outcomes such as how efficient or effective is the governance in meeting pre-determined objectives (Box 8.2).

[Insert Box 8.2]

Governance has three core functions:(i) To identify what is the `optimal'  institutional structure; (ii) To manage institutions, which implies monitoring, sustaining, fine-tuning, and facilitating of all these activities (iii) to change the existing institutions or bring about newer ones to close the gap between the existing and the `optimal' structures. Institutions are the formal and informal rules, including norms and practices. Organizations are not institutions but actors within institutions. Institutions often include markets too. However non-market or meta-market institutions are also required for AKST investments because of multiple forms of market failures. Some of these market failures are observable in any R&D investment requiring institutional interventions such as patent rules. In general, market failure arise from the public good nature of some forms of AKST, implying that it is very difficult or costly to exclude people who are not willing to pay for the technology from using it (Norton, 1991; Stiglitz, 2000).

The framework for assessing governance of AKST systems comprises of a set of characteristics that the outcomes of institutional interventions mediated through good governance is expected to have. These are briefly discussed below to provide clarity of the analytical framework:

- Good governance should address identifiable market failure problems, in order to allocate public resources in areas where uncoordinated action of private individuals would be inadequate or inappropriate. Nonetheless, correcting market failure is only justified where the losses from the failure are higher than the cost of correcting it, including both direct and indirect costs of institutional intervention. Where there are multiple forms of market failure occurring at different points of the technology development process, each failure must be addressed accordingly.
- Where agricultural growth is not the constraining factor to poverty reduction or to attaining economic growth, prioritization of appropriate intervention among sectors or between agricultural research and other interventions within agriculture is another important outcome. There may be cases where factors other than R&D become binding constraints to agricultural competitiveness (Garelli, 1996). The appropriate level of resource allocation for agricultural R&D is also related to sectoral prioritization (Tabor et al., 1998). AKST decisions are made by many actors; each of them takes into account the expected action of others. For example, poor and small developing countries may want to depend on international technology transfer and this may be the best option for certain

technologies in order to avoid unnecessary and costly duplication of efforts (Tabor et al., 1996). However, such dependence may not always be possible for tropical countries, whose commodities (crops, livestock, fisheries, and forests) are unlikely to be cultivated or raised in the industrialized world.

- Good governance should ensure that institutions and organizations (as well as individuals who work within these organizations) serve the intended purpose effectively and efficiently under all conditions. The achievement of efficiency in research investments is complex due to problems of economies (some times diseconomies) of scale and scope, which determines the required degree of specialization or diversification of specific research organizations. These considerations may also lead to contracting out or contracting in of specific activities, and also the extent of decentralization in decision-making. The role of governance is to enable the internalization of such efficiency concerns in decision-making. This requires design of institutions with: (i) The ability to shape specific objectives to suit socioeconomic realities. This implies that there should be mechanisms to discontinue research programs that are no longer acceptable to stakeholders. (Sometimes inefficient institutions may continue to persist due to path dependence and lock-ins. Meanwhile, efficient institutions have a built-in ability to adapt to changing realities through feedback.) (ii) The ability to meet the objectives with reasonable assessment of risk and uncertainty. (iii) The ability to assess current and potential future demands of AKST investments. (iv) The ability to carry out assignments and tasks in the most efficient manner, which entails producing given output at the cheapest possible cost or achieving maximum output for a given cost. Higher institutional efficiency can be achieved by aligning the incentives of actors to be in tune with institutional objectives, which in turn should change with evolving economic environment.
- Good governance should aim at following procedures that ensure transparency and accountability for minimizing mistakes and errors of judgment to ensure that broader societal priorities are reflected in decision making without being captured by distributional struggles of narrow interest groups. For example, although local scientists may be better informed about national agricultural priorities, their decisions on funding priority may be biased towards maximizing the flow of funds to their own area of work (Tabor, et al., 1998).

There can also be process-based criteria for good governance, where the concern is not only on outcomes but also on how these outcomes are produced. For example, participation of specific stakeholders can be viewed as important for efficiency or effectiveness of outcomes but also as an important element on its own, with the assumption that pursuing participation is good irrespective of its impact on efficiency or effectiveness. Thus there have also been arguments that good governance should follow certain procedural correctness which should permit

- Negotiation of diverse interests and the identification of common interests;
- Negotiation of clear rules and norms among multiple stakeholders, their effective implementation and the setting-up of control mechanisms for compliance to these rules and norms;
- Equitable access to resources (economic/financial, human, natural, social, physical) and AKST;
- Participation in strategic decision-making of all relevant stakeholders;
- Adequate equilibrium among power forces in decision-making and implementation of strategic decisions, and
- Capacity to influence policy making.

Governance can also be viewed at multiple levels; at the level of a research station, a national research system, a regional research network as well as at the global level. When we analyze the issues of governance of a research station, we take the external environment including the objectives given to the station as exogenous, and try to see how the governance of the station can be improved to meet these given objectives within the resource constraints. One can also analyze the larger question of governance at which one critically looks at whether the objectives defined by, or resources given to the station are appropriate and meet the criteria of good governance. Based on the conceptual framework as given here, one can develop a set of questions that are relevant for analyzing the governance of, and institutions involved in AKST investments (Table 8.19).

[Insert Table 8.19]

8.3.3 Analyzing the experience of governing AKST investments

8.3.3.1. Public funding /public sector research

The model of public sector research organization came to exist in many parts of the world during the second half of the nineteenth century. The founding of the public research organization was based on an assumption that nongovernmental agencies (including private firms and farmers themselves) are unable to mobilize adequate resources and skills required to generate agricultural research (see also 2.2.2). It was then assumed that farmers generally needed to be educated on the benefits of new technologies and did not have any major role in the generation of technology directly. Thus government, either national or regional, provided the resources for the establishment of these research establishments from the taxes, international aid or other assets such as state-owned land. This perception of the farmer, however, has changed in recent years.

Investment for AKST by governments has been successful on certain counts. It enhanced the capacity of a number of countries to carry out good quality research. In many poor countries, there would not have been any significant level of agricultural R&D without these institutions due to the limited capacity as well as inadequate interest of the private or not-for-profit sectors to provide agricultural R&D, which mostly falls in the public good domain. Government-funding for AKST has also played an important role in enhancing the awareness of farmers, in creating a wide pool of trained personnel and informing policy making at the national level in a number of countries.

Despite such achievements, this model has had several problems. For example, it did not perform well in assessing the needs of farmers in many parts of the world and it has been fairly slow in responding to social and economic changes. There have been innumerable cases where research investments were directed in a way that they failed to meet set objectives, even if the uncertainty inherent in R&D activities is accounted for. Public organizations were not very successful in taking into account local agroclimatic and socioeconomic features in their research programs (Santhakumar and Rajagopalan, 1995). Efficiency of public R&D organizations is also open to question, and one feature noted in many developing countries is the spending of a greater amount of financial resources to provide the salary of permanently employed staff, with little left for actual research activities, which in turn affect the research output and hence the research efficiency (Eicher, 2001). This may not be directly evident in ROR calculations of agricultural research. It is possible to have high ROR even with these levels of inefficiency. There have been inappropriate resource allocations between capital and operating expenditures in the public sector, resulting in a pool of inadequately trained and equipped personnel, research laboratories without sufficient operational and maintenance funds, or other inefficiencies.

The fiscal problems of the governments of many developing countries have led to a reduction of resources made available to public research systems, which often reduced the funds available for recurring and operating costs (Premchand, 1993; Eicher, 2001). The rewards of the agricultural staff tend to be misaligned leading to difficulties in keeping the best talent on the one hand, while the indexed salaries of employees without much concern for market wages tend to balloon the overall budget for this purpose. There is also the widely discussed problem of wage erosion, meaning the loss of salary purchasing power, which impacts negatively on commitment and morale of research staff.

Sometimes allocations of public resources can lead to spending being spread too thinly across commodities, regions and research themes. There can also be other inefficiencies within public organizations leading to wastage of resources, corruption and poor planning in public funded research. Public sector scientists can continue with research on commodities (crops, livestock, and natural resources) and technologies even when farmers move out of these areas due to economic reasons. Some studies show that returns to public sector agricultural extension became low due to the multitude of “non-extension” duties, and that extension agents were not the main sources of technical information to farmers (Isinika and Mdoe, 2001).

During the 1980s, public research models were reformed to become more participatory. This was to make public research organizations more responsive to the requirements of farmers, especially those that are poor and live in resource-deprived areas (Kaimowitz, 1993). Only limited successes were achieved through such participatory research models. This could be due to the fact that the structure of public research organizations was not reformed. The channels of priority setting do not correspond to the funding channels, in other words, funding is provided from other sources than those setting research priorities (Hartwich and von Oppen, 2000). Another reason could be that the incentives for individual researchers were not always adequately oriented to participatory research. These incentives include not merely additional money but also additional facilities to carry out participatory research, but also intangible ones.

Public research organizations have also responded to the criticisms on their inefficiency by adopting impact assessment of their efforts, priority setting exercises, and also the introduction of operation and management reforms through measures such as decentralization, accountability, transparency and cost recovery among others (Hall et al., 2000). Moreover there have been efforts to give more autonomy to research organizations, remove them from civil service regulations and to provide greater flexibility to manage their physical, financial and human resources (World Bank, 2000). One can see such examples from the industrialized world. There has also been decentralization of research and extension systems in developing countries including Uganda, Tanzania, Kenya, Zambia and Ethiopia (Anandajayasekeram and Rukuni, 1999). Similar examples of more pluralism in AKST systems were documented for various other African and Latin American countries (Shao, 1996; Byerlee, 1998; Echeverria, 1998; Heemskerk and Wennink, 2005). But the experiences in different countries are mixed. Research practices and administrative and financial procedures of national research systems have not witnessed any major changes in a number of countries. On the other hand, reforming compensation in the national agricultural system of Chile has made the public research sector more attractive to talented agricultural researchers (Venezian and Muchnik, 1994).

The resource allocation for public sector research, though ideally driven by considerations of social welfare, is determined in reality by the political economy[9] , i.e. the struggle between the

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[9] The term political economy is used within the framework of `new political economy' (e.g., Bardhan, 1997) .

interests of different societal sections (social groups, regions, growers of specific crops, gender), and also those who dominate decision-making. Evidence from different parts of the world indicates the influence of such political-economy factors in resource allocation for agricultural research. Research and extension spending is linked to the political effectiveness of farm interests (Rose-Ackerman and Evenson, 1985). A study of 37 countries show that structural changes in the economy have important effects on the political incentives to invest in public agricultural research (Swinnen et al., 2000).

Thus even when agricultural research provides higher returns or has the potential to reduce poverty; it does not get enough investments in the public allocation of resources. Sometimes ideological considerations lead to high priority being placed on certain crops, thus making investments economically inappropriate. For example, perceived notions of food security in certain states of India have led to excessive research investments on food crops even when the region is inappropriate for those particular crops, and hence farmers adopt, diversified commercial crops (Santhakumar and Rajagopalan, 1995; Santhakumar et al., 1995). Gender is an area where political economy influences research investments and outcomes. This manifests itself in certain situations through inadequate investment in research on crops cultivated by women or technologies which would reduce the drudgery of female agricultural workers. In certain other situations, new technologies produced through research lead to the displacement of women workers. An example is access women to ICT, which may be limited because of their reduced physical access to resources and infrastructure, social and cultural norms, education and skills, and poverty and financial constraints (Hambly Odame et al., 2002).

Does democracy help in achieving the socially desirable objectives through AKST investments? There is no straightforward answer evident from the literature (for example, Diamon and Plattner, 1995) on whether democracy vs the responsiveness of governments has a higher degree of such achievement. Even in democratic countries the political process can be captured by narrow interest groups, whose goals do not necessarily aim at overall social welfare. Even if the role of such groups are controlled, democracy is likely to be driven by the preference of the median voter, and there are situations in which the interest of such a voter need not be in tune with the maximization of the overall welfare of the society. Thus, though democracy is valuable by itself, and provides greater opportunity for wider participation in political decision-making, there is no assurance that it will lead to decisions that enhance the welfare of the society as a whole. The lesson for AKST is that democratic governance is not sufficient to ensure effective and efficient investments aimed at achieving larger development goals.

8.3.3.2. International donors

Broadly, international donors are motivated by three objectives in extending funding for ASKT to developing countries. These are:

- International charity or resource transfer based on altruistic considerations;
- Correction of international market failure or the provision of international public goods; and/or
- Expansion of the markets of the donor countries.

These objectives have motivated international donors to support agricultural research and extension capacity to enhance food production in many developing countries during the last 50 or more years.

Although international funding for AKST is a major source of support in the developing or poorer countries and domestic research would not have developed without this crucial support, international funding can also create distortions. The availability of international funding at times may encourage domestic players not to mobilize internal resources, which is needed if and when international sources withdraw their support. This is most visible in Africa where donor support to agricultural research has increased in relation to domestic support so that nearly half of the agricultural investment in Africa is from donors including development banks (see 8.1.4). This has perpetuated donor dependence and undermined efforts to develop domestic political support for sustainable funding, especially for the smallholder sector (Rukuni et al., 1998; Eicher, 2001). The allocations of international funds between different types of expenditures, such as between capital and recurring costs do not need to adequately reflect the domestic opportunity cost of the resources. There have been instances where external aid has compounded the inefficiencies in AKST investment decisions in developing countries. The risk of bad investment goes up when grants are easily available (Tollini, 1998).

Correcting market failures at the international level could be another force driving international donors to fund AKST systems or generation. There are at least two major forms of market failures. There can be international negative externalities, which need action at the international level, but there may also be instances where it is efficient for the international community to take action to address certain problems within the developing countries that have the potential for global impact. The recent incidence of avian flu is a good example. Even if the interest in the industrialized world is to protect itself, financing some activities in developing world on preventative measures at the source of the problem would be a more effective and efficient strategy rather than spending money only on protective activities within the industrialized world. Similar arguments apply for international public goods. Certain technologies or technology generation systems themselves can be seen as international public goods. The ideal strategy would be for the industrialized and developing world to pool their resources together, but there are problems of coordinating such efforts. The severity of lacking such public goods perceived in the industrialized world would encourage them to take proactive steps, whereas developing countries who face other more pressing problems would give low priority. How far AKST investments driven by the requirements of correcting international market failure reflect the economic variables of the world as a whole, would determine their effectiveness, efficiency and outcomes. Moreover, it is important to see that such investments made in the developing world do not create distortions in their economies.

The expansion of markets or cost-reduction of global production has also driven industrialized countries, multinational firms and multilateral agencies to make AKST investments in developing countries. These, however, raise a number of issues: (i) Trade and nontrade barriers (and associated transaction costs) might influence where such investments take place and at what cost; (ii) Since the domestic institutions in many developing countries are weak, this may lead to an intensification of `market failure' problems in such countries. For example, there are apprehensions on increasing field research of new (genetically modified) seed varieties in developing countries as part of international contract research, without taking adequate safeguards against the unknown long-term impacts of such seed varieties and also for the preservation of local genetic materials.

The urge to expand the lending of multilateral funding agencies has also received criticism during the last decade. The incentives of the personnel in these agencies could be directed towards excessive lending, and this, combined with the incentive' of political and administrative decision makers of developing countries to borrow excessively (more than what is warranted by the domestic economy considerations), can lead to excessive loans. Whether this incentive problem has affected the efficiency of multilateral funding for AKST in developing countries is an issue that needs to be analyzed.

8.3.3.3. Competitive funding

Block grants have been used for allocating research resources for many years. Now block grants have become less attractive as concerns have been raised about inefficiency in resource allocation, effectiveness and relevance of research as well as exclusion of other stakeholders in the research process, from priority setting to execution of research projects/ programs (McMahon, 1992; Echeverria, 1998; Reisfschneider et al., 1998; Von Oppen et al., 2000). This has led to the gradual evolution of competitive funding mechanisms at the international and national levels. Competitive grants;

- Allow for a wider network of actors to participate in the research process broadening the scientific talent available (Von Oppen et al., 2000);
- Allow for a possibility to seek a diversity of funding sources (Byerlee, 1998);
- Improve research quality (Byerlee and Alex, 1998);
- Improve allocation of research resources (Alston et al., 1995).

However, competitive funds have the disadvantage of having high transaction costs (Echeverría, 1998). Competitive grants take scientists’ time (funded through core funding) for preparation of research proposals, and evaluation (Huffman and Johnson, 2001). There is also significant increase in administrative costs for managing research competition. Another disadvantage of competitive grants is that they do not contribute to capacity development in terms of infrastructure and human capital development. They also tend to be of short term in nature, which may divert attention from more crucial research topics and national priorities (Echeverría, 1998). It has been noted in Africa that competitive grants (i) fail to include beneficiaries in the research process (ii) fail to prioritize and hence tend to spread resources too thinly (iii) create uncertainty as to whether the funds are truly competitive and are able to link to performance, given the limited number of researchers in the region (iv) are expensive to operate; and (v) are not sustainable without external donor support. The inherent ex-ante uncertainty in research, asymmetric information that makes monitoring of scientists by administration difficult, and the sharing of risk between funding agencies, administrators and scientists are issues that may make contract-oriented reforms in R&D complex even in industrialized countries.

8.3.3.4. Commodity boards and growers’ associations

The growing role of commodity boards, producer-funded or growers' associations, in research is also a related development. Nonprofit organizations constitute a comparatively large share of agricultural research in Colombia and some Central American countries (Beintema and Pardey 2001). Colombia has twelve nonprofit institutions, which accounted for about one-quarter of the country’s agricultural research investments during the mid-1990s. Many of these agencies began conducting research several decades ago and are funded largely through export or production taxes or voluntary contributions (Beintema et al., 2006). In Africa examples include agencies conducting research on tea (Kenya, Tanzania, Malawi, Zimbabwe), coffee (Uganda, Kenya, Tanzania), cotton (Zambia), and sugar (Mauritius, South Africa). There are, however, other forms of nonprofit institutions in a number of countries, including Madagascar and Togo, although these play a limited role in agricultural research (Beintema and Stads, 2006). There is no evidence that the involvement of growers' associations or private sector has added more investment for AKST or have been replacing government funding.

How far research driven by these agencies is different in terms of efficiency and effectiveness from that in state-funded organizations, especially in the developing world, is a question requiring further investigation. In tea research in India the R&D carried out under planters' association leads to the development of appropriate technology due to the greater awareness of clients' requirements, and faster or timely communication of these technologies to the users (Muliyar, 1983). If commodity boards have also a mandate for marketing and/or the provision of other support services (including subsidies), they may have a greater incentive for being effective in terms of technology generation and extension, even if these boards function under the government (Narayana, 1992). In Kenya, acceptable ratios of personnel/operations cost prevail in coffee and tea research, which is financed by a cess. But there are also cases in Kenya where growers associations became politicized and hence being less accountable to the growers (Kangasniem, 2002).

One concern is that the producers' associations or commodity boards focus on the sole benefit to producers and thereby mostly neglecting the welfare of the consumers and the economy as a whole. It is not uncommon to see the growers associations and commodity boards lobbying for enhanced protection of their products in domestic markets or support for exports, both of which may have a negative impact on domestic consumers. Moreover, the provision of subsidies associated with the propagation of specific technologies, as well as the bureaucratic compulsions of commodity boards may also lead to excessive inducement of farmers to adopt specific production systems, which may not be sustainable in a more market-determined situation. Finally, it is possible that producer organizations may not be the best suppliers of research services except for adaptive on-farm research (Echeverria et al., 1996). These shortcomings provide a justification for continuation of government funding for basic and strategic research even in industrialized countries. Moreover, for crops that have a large number of cultivators such as rice or wheat, the concept of growers' association becomes unmanageable and would have problems similar to those of government-owned research. Additionally, to what extent the small farmers are represented by these associations remains unclear and depends on the commodity and the countries.

8.3.3.5. Private research

In the industrialized countries and the more advanced developing countries, the inadequacies of the public research model led to the gradual emergence of private sector (or broadly market-oriented) reforms in agricultural R&D investments in the late seventies and eighties. This was facilitated by the interests and the capability that the private sector has developed in AKST investments. The structural adjustment policies implemented in many developing countries,[10] the global changes in trade regime and developments in biotechnologies, have also facilitated this transition.[11] This transition is manifested in the increase in private sector funding in public sector organizations and universities, and the increase of the research directly carried out by private sector organizations. The commercial or application-orientation of the private sector to some extent fills the gap between technology generation and extension that existed in the public research model. There has been an increasing involvement of the private sector in agricultural extension as well (Umali and Schwartz, 1994).

There are variations between countries and regions in terms of the contribution of private sector in agriculture research (see 8.1.1). Though private sector investments play an important role in OECD countries, their share in many developing countries continues to remain insignificant. Not surprisingly, there may be a linkage between national income of the countries and the role of the private sector in agricultural research (McIntire, 1998). But the lack of significant private research is also often the result of the legal and administrative environment in many countries (Ahmed and Nagy, 2001).[12] There are indications that mutually negative perceptions of public and private players, unresolved issues of risk and liability, high transaction and opportunity costs act as barriers against the development of public private partnerships (Spielman, 2004; Spielman and Grebmer, 2004).

Each of these funding mechanisms has advantages and disadvantages. In developing countries where governance structures are still weak, the advantages may not be apparent during initial stages of the funding options (Box 8.3).

[Insert Box 8.3]

8.3.4 AKST governance and changes in the larger institutional environment

So far we have considered only the institutions directly governing AKST investments. However the broader institutional environment encompassing the ownership of rights over land, water, and other common property resources would also influence indirectly the governance of AKST investments. The institutions under this category can include land reform, water management, forest protection, international standards related to food products and agricultural imports, international law of the seas, global agreements on climate change and so on. These institutions

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[10] See Tabor (1995) for a number of articles dealing with the impact of structural adjustment policies on agricultural research system.

[11] Private sector involvement in agricultural biotechnology research started much before, and by the 1990s, private sector investment in this regard has exceeded that of the universities and government owned laboratories (Lewis, 2000).

[12] On the other hand some countries (for example, Thailand) seem to have government policies favorable to private sector research.

that set the rules for managing natural resources locally, nationally and internationally would have a direct bearing on the effectiveness, nature and content of AKST investments. Similar is the impact of emerging organizational forms in the trade of agricultural and related commodities. For example, contract farming for export-oriented horticultural crops is expanding in many developing countries, and this will have a bearing on how AKST is generated and used, and consequently how investments are made for this purpose (Porter and Phillips-Howard, 1997; Haque, 1999). It is not only that the effectiveness of AKST investments is influenced by institutions governing natural resource management and use, but, increasingly AKST investments are also seen as solutions albeit partially for sustaining the natural resource base. This is especially important in a context where urban and environmental interests in resources such as land and water compete with farming interests (Farrell, 2004). AKST investments and the institutions of natural resource management are in turn influenced by the wider political and economic institutions of countries and the world. The market expansion in developing countries,[13] changes in world trade regime,[14] structural adjustment policies in many countries, and others are going to influence not only natural resource management but also investments in AKST.

In addition to these institutions, the way human consumption especially that of food and agricultural commodities changes in the future would have a strong influence on the nature of AKST investments. Though economic variables such as income play an important role, social, cultural and ideological factors do have significant influence on the evolution of human food and consumption systems. There need not be a linear evolution from traditional and home-based subsistence consumption to a full reliance on globally integrated markets for commodities produced with factory-based inputs and modern technology. There are indications from India and China that economic growth and development do not lead to a decline in (if not an increase of) the demand for the so-called traditional systems of food-making or nature-dependent health care systems. This underscores the importance of visualizing different scenarios of future and their likely influence on the investments of AKST. However one probable scenario on the governance of AKST in the near future is outlined below.

8.3.5 The future roles of governance and institutional structure

In many developing countries the domestic private sector may continue to play only a small role in the near future. Even in industrialized countries, the new set of research instruments is not going to replace the conventional public research model. It is envisaged that there will be a

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[13] Poorly developed market infrastructure can influence the distribution of gains from agricultural research (Dasgupta and Stiglitz, 1980).

[14] The opening up of an economy may make farmers' price takers, and hence they may become less capable of being the major beneficiaries of agricultural innovations. Changes in trade regime may have a greater potential in changing the distribution of direct benefits of agricultural research in a country than other routes such as better targeting of agricultural research expenditure (Voon, 1994; Sexton and Sexton, 1996).

combination of public and private investments with the latter increasing over time. The additional costs associated with competitive funding would encourage the persistence of a combination of conventional forms of funding (such as formula funding) and competitive grants in the near future. However competitive funding as a mechanism complementary to the regular budgetary support seems to be inevitable (Gage et al., 2001), or project funding and institutional grants may have to coexist (Becker, 1982).

Similarly one should not expect that the private sector is going to replace the public sector even in areas such as agricultural biotechnology in which private organizations have an upper hand. Private sector research will concentrate on areas where (a greater part of the) benefits can be privately appropriated as in export or plantation crops, hybrid seed development or in off-farm processing of agricultural products, and in the diffusion of capital goods such as agrochemicals. For example, USAID recognizes that the private sector will not deliver biotechnology applications for many crops (such as minor or food security crops), will not address all biotic and abiotic production constraints, which are important in developing countries nor will it realize the development of commercial markets in all developing countries (Lewis, 2000). Public sector research will have to fill these gaps. Moreover, some of the conventional market failures associated with agricultural R&D are still important and hence some form of societal or state intervention may continue to be necessary. Some of these market failures, which make private investments alone inadequate, are the following.

- Given the scale economies in specific research initiatives, competition and existence of multiple firms may not be economical. This would lead to monopoly powers of the existing firms, which would warrant certain regulations to remove entry barriers in order to avoid social losses;
- Given the features of positive externality or public good associated with the development of agricultural innovations and knowledge, it is very likely that there can be under-investment (less than the socially optimal levels) by private firms in such cases. This may be particularly so in the creation of what can be called basic or pure knowledge where the appropriation or excludability problem is acute;
- Certain innovations or technologies may have negative externalities especially with regard to environmental pollution or long-term health hazard. This is an area where institutional intervention by the state or society is required to make the private firms internalize these externalities;
- There can also be a distributional issue which would prompt governments to intervene (that need not necessarily be through state-owned research organizations) to see that technologies that help poorer farmers living in less resource-endowed areas (for example drought prone) are also generated. It is argued that the disbursement of funds in public

sector research through competitive grants is likely to generate regional disparities as well as less money for activities such as managing natural resources and the environment, which need not be profitable in market value terms. This too can encourage public support for research, which are not solely based on commercial considerations;

- Agricultural research has to stand on the firm foundation of higher education. In many countries, including those in the industrialized world, higher education in AKST is closely linked to research laboratories. Higher education is unlikely to thrive solely on profit-oriented investments. This would necessitate the functioning of public/private organizations involved in agricultural research based albeit partially on public funds and endowments or other nonprofit oriented investments.

However it is very likely that there is more and more rethinking on the specific roles governments (both national and local), funding organizations and public sector research organizations in AKST investments. It is quite possible that state-owned institutions devote more resources on technologies to be used by the poor, and also on environmental conservation and other related areas where due to the externalities, private firms are less likely to invest adequately. (This is based on the assumption that the distributional struggles, political economy and the overall governance, including the role of democracy, are such that poverty reduction and mitigation of externalities become priorities of the governments.) In future there will be more and more public private partnerships in agricultural research and here the experience from OECD countries seem to be successful in making research systems more responsive to the rapid transformation of economy and their innovation requirements (Guinet, 2004). There are multiple ways of enlisting private partnership in public research and here the choice of mechanisms is very important to enhance the overall benefits. Governments and public sector organizations may be more involved in regulation and quality control of products and technologies developed by the scientists from both public organizations and private firms. Scientists may have to encounter more competition in getting research funds not only from international organizations but also from their national governments. The labor market for scientists may also become more flexible with shorter-period incentive-based contracts rather than permanent jobs. Though there is evidence that participation by private partners enables publicly funded research to concentrate on areas where private incentives are weaker (Day-Rubenstein and Fuglie, 1999), care is needed to ensure that institutional changes in public sector and changing sources of funding do not undermine the research agenda of public institutions, especially the generation of knowledge, which may not seem to be profitable and viable by the private firms.

8.4 Investment options

The goal of this international assessment of AKST is to provide policy makers with investment options for meeting the development and sustainability goals. Since no single investment can meet all goals at once, a portfolio of AKST investments are needed. Countries are likely to have different weights on the importance of the different objectives and so alternative combinations of AKST investments will be presented based on whether countries place more weight on environmental goals, improving health and nutrition, reducing poverty and hunger, or maximizing economic growth.

This subchapter focuses on the research investment options of governments, international organizations, and foundations that support AKST in order to achieve development and sustainability goals. The questions that these organizations would like to be answered include:

- How much should governments invest in AKST versus other public goods?
- How should AKST resources be allocated? Which commodities? Where—for example, less favored land, small poor countries? What type of technology—for example, labor using, land saving, or water saving technologies? Which disciplines? Which components of AKST? Which institutions?
- What methods should be used to decide how much money to invest and how to set AKST priorities?

The answers to the first two questions need to incorporate multiple criteria, which should include at least public RORs to research as well as the impacts on poverty, human health, and environment (see 8.2). Societies and policy makers who place more emphasis on poverty reduction rather than economically sustainable development or environmental sustainability could place more weight on the AKST investments that reduce poverty than societies that favor improving the environment. Societies with more poor people may place more weight on research to improve the livelihood of the poor than on research to reduce greenhouse gases Countries in which agribusiness plays a big role in the economy and a large role in governance of the public research institutes, may invest more in developing productivity-increasing change

Formal priority-setting methods, including those based on ROR studies, are in practice only occasionally used to set research priorities, and formal multi-criteria techniques for research resource allocation are used even less (Alston et al., 1995). This is because they are expensive, time consuming, and some factors are difficult, if not impossible, to quantify. The impacts of agricultural research on environment, health and poverty have been particularly difficult to measure (see 8.2.5, 8.2.6, 8.2.8). As a result, most of the studies that we were able to assess and base our policy options on are those of the ROR type. However, making mistakes when investing in AKST can also be a problem - investing money in an AKST project that has little social or economic importance, large negative consequences, or very little chance of succeeding can be even more expensive than formal priority setting. Thus, investing in formal priority setting can save money and have high payoffs. Changes in governance that incorporate users of this technology into the priority setting and evaluation processes can also be productive.

When looking forward – particularly 50 years forward – people who decide on AKST investments often simply have to look for major problems that appear to be coming and invest to fill gaps in knowledge.

8.4.1. Criteria and methods for guiding AKST investments

"Any research resource allocation system, regardless of how intuitive or how formal in its methodology, cannot avoid making judgments on two major questions. What are the possibilities of advancing knowledge or technology if resources are allocated to a particular commodity, problem or discipline? What will be the value to society of the new knowledge or the new technology if the research effort is successful?" (Ruttan, 1982).

ROR studies and broader comprehensive impact assessments can be undertaken before initiating any AKST investment (ex-ante) or after completion of the R&D activities (ex-post) depending on the purpose. The purpose of undertaking ex-ante assessments is to study the likely economic impact of the proposed investment, to formulate research priorities by examining the relative benefits of the different AKST investments, to identify the optimal portfolio of investments and to provide a framework for gathering information to carry out an effective and efficient ex-post assessment. Thus the greatest benefit of ex-ante assessment is derived from its power to assist decision makers to make informed decisions on investments i.e., in setting priorities to allocate the scarce resources.

AKST investment priorities are set at both micro and macro levels. More formal quantitative methods are used at the macro level and participatory methods are increasingly being used at the micro level. Priority setting is carried out explicitly or implicitly in all AKST investments through allocation of research resources to different commodities, regions, disciplines problems and type of technology. Since priority setting occurs at various levels of decision making, the resource allocation questions and methods employed vary depending on the level at which priorities are set. Priority setting also requires intensive consultation among and between politicians, administrators, planners, researchers as well as the beneficiaries. Formal procedures facilitate this process as they systematize the consideration of key variables and multiple objectives in the analysis and allow an interactive process to develop.

Priority setting based on ex-ante assessment employs a range of methods that can be broadly classified into supply-and demand-oriented approaches; although some combination of these approaches is often used in empirical studies. Supply-oriented approaches to priority setting and resource allocation often are conducted at the more aggregative regional and national level and use a variety of methods from informal methods based on previous allocations; discussions and consensus among research managers taking into account national agricultural goals and strategies; to formal quantitative methods such as scoring models, congruency analysis, domestic resource cost ratio, mathematical programming, and simulation techniques. The more sophisticated approaches such as programming and simulation rely on mathematical optimization of a multiple goal objective function to select the optimum portfolio of AKST investment. These are data and skill intensive and thus often quite costly to undertake. Many attempts have been made in the past to use a formal priority setting exercise to ensure that research resources are allocated in ways that are consistent with national and regional objectives and needs. Studies which have been undertaken to assess ex-ante AKST investment priorities have included those employing criteria which include equity and distributive concerns (Fishel, 1971; Pinstrup-Andersen et al., 1976; Binswanger and Ryan, 1977; Oram and Bindlish, 1983; Pinero, 1984; Von Oppen and Ryan, 1985; ASARECA, 2005) those focusing more on efficiency criteria such as congruency (Scobie, 1984); those employing the notion of comparative advantage using domestic resource cost analysis (Longmire and Winkelmann, 1985): those using economic surplus to examine research priorities (Schuh and Tollini, 1979; Norton and Davis, 1981; Ruttan, 1982; Davis et al., 1987, Omamo et al., 2006), and those using an optimization routine (Pinstrup-Andersen and Franklin, 1977; Mutangadura, 1997). One of the most comprehensive studies of research resource allocation lists methods for allocating research resources (Alston et al., 1995). These combine information from scientists, technicians and other experts on the expected output of science, their probability of success and possible timelines with information from economists and other social scientists on what the potential economic and social payoff would be if the research investment is successful. The formal methods have been extended to include environmental consequences of AKST investments (Crosson and Anderson, 1993). The overall aim is to foster consistency of research priorities with goals and objectives and to improve the efficiency of the AKST investments in meeting the needs of the producers, consumers and society at large.

In demand–oriented approaches, priorities are set based on the perspective of major stakeholders from outside the research system – especially the users. These might employ consultative and participatory methods using various forms of ranking techniques or users themselves might be empowered to make decisions on research priorities. However, it is worth keeping in mind that demand-led and supply-led approaches are not mutually exclusive. Better results can be obtained by combining formal supply-led priority setting with participatory approaches leading to better ownership of resulting priorities and greater chances that the priorities will be translated into actual resource allocation. Even the imperfect participation and empowerment of beneficiaries is likely to produce better results than conventional supply-led approaches on both efficiency and equity grounds, as they can improve the probability of broad-based adoption of technologies and knowledge generated, thereby enhancing innovation capacity. The challenge is to develop a judicious blend of bottom-up (demand-led) and top-down (supply-led) approaches to priority setting incorporating the multiple goals of AKST investments.

Formal models exist for the ex-ante evaluation of research projects, which are being used increasingly in more industrialized countries to allocate research funds but this is less common in developing countries (Pardey et al., 2006b). Few formal ex-ante models incorporate the goals of reducing poverty and hunger and the environmental consequences as explicit criteria for allocating research resources. Some progress has been made recently to incorporate these aspects in the analytical process. The two ex-ante studies reported in Eastern and Southern Africa (ASARECA, 2005; Omamo et al., 2006) consider the ex-ante benefits of all major commodities and the economic and poverty reduction potential of research investments. In addition, there are specific studies on site-specific maize research in Kenya (Mills et al., 1996) and the research priority setting under multiple objectives for Zimbabwe (Mutungadura, 1997; Mutungadura and Norton, 1999). The extent to which such results are actually used for setting the R&D agenda remains unclear. These approaches (based on expected costs and benefits) are very useful in allocating resources among applied and adaptive research programs and projects. However, they are of very little use to allocate resources between basic, strategic, applied and disciplinary research.

It is not just methods per se that are problematic; it is also the ability of would-be analysts gaining the requisite skills to use what methods are available. In the context of NARS, the task of developing the needed capacity to address aspects such as environmental and economic assessment of agricultural technology consequences on NRM (Crosson and Anderson, 1993) is still not yet adequately developed, especially in an era of profound under-funding of research, at local, national and regional levels. An important issue in developing and implementing AKST investment priorities is to explicitly incorporate the requirements of those who are expected to benefit from such investments.

Our approach in this study, which presents the empirical evidence available on the economic, health and environmental impacts of research but does not try to use a formal priority setting process to weight the importance of different criteria, reflects the discussion of well-intentioned, but often misguided attempts to deal with such multi-criteria formulations of research priorities (Alston et al., 1995). The review of methods based on scoring models suggests that there are definitely methodological challenges in such work yet to be satisfactorily dealt with. This fact shows the need of more resources to develop easier and more effective evaluation methods that can include environmental and societal (poverty, nutrition and health) impacts, both positive and negative.

8.4.2 Investment options

The ideal social planner would be able to rank research investments by their expected contribution to economically sustainable development, decreased hunger and poverty, improved nutrition and health, and environmental sustainability; and then would solicit weights from society based on the relative value society places on these expected contributions. Each country will have different weights based on the governance of the system and the countries' available resources, their culture, their institutions and their technology. More investment in AKST can make important contributions to the goals of economically sustainable development, hunger and poverty reduction, environmental sustainability, and improvement of nutrition and health.

The private sector will not make major investments in the provision of public goods, poverty reduction, and the provision of environmental services and health services for which there is no market (see 8.3.5). Therefore most governments, especially in developing countries, need more public sector investments into AKST that will produce public goods and services necessary to reach development and sustainability goals. Few countries are likely to reach the 2% research intensity level of OECD countries, but they will need a major increase in investment in agricultural research intensity from the current level of 0.5% (see 8.1).

As reported in 8.2.8, studies of seven countries in Asia and Africa showed the returns to agricultural research were high relative to other investments that countries could make such as irrigation, roads, electricity, and other government programs (Fan et al., 2000, 2004ab, 2005; Fan and Zhang, 2004). Agricultural research was one of the leading investments that governments could make to reduce poverty. Research by itself will not lead to poverty reduction, but it can be an important component of a poverty reduction strategy. The other component of AKST in these studies was primary education which also made a major contribution to poverty reduction. The evidence shows that research alone cannot reduce poverty and thus, funding for AKST must be accompanied by other pro-poor policies, such as access to natural resources, equity of distribution, good governance practices, and local market development.

Projections in chapter 5 of this report show that the baseline scenario will have a limited impact on reducing child malnutrition – it would decline 15% in the reference world (see 5.3.3). However, with increased levels of AKST investments accompanied by other complementary investments, the share of malnourished children is expected to decline. In addition, projections suggest that returns to research will stay high. Under the business-as-usual scenario, the demand for agricultural products will continue to grow rapidly in the next 50 years; resources that are now used to produce agricultural products will be increasingly in short supply - water, land, and clean air; and basic science will move rapidly ahead creating new opportunities for applied science and technology, which will also increase returns to research.

An additional factor that will be required to keep returns high is good governance (see 8.3). Specifically, the farmers, who will be the primary users of the research, must be included in determining how public money is invested in AKST and how that funding is allocated. In addition, consumers of food and other ecosystem services from agriculture must be represented. Finally, the private sector, which provides inputs to the agricultural sector and purchases, markets and processes agricultural products, must also be represented.

Private sector investments in agricultural research, innovation, and diffusion of technology and management systems in developing countries are also essential to meeting development and sustainability goals (Pray et al., 2007). While the private sector will not make major investment in the provision of public goods and poverty reduction for which there is no market, private agricultural input companies can be an efficient way to provide poor farmers with inputs such as improved seeds and livestock, which can help improve the incomes of the poor and other private companies can develop and supply farmers with inputs needed to increase their supply of ecosystem services (see 8.1.2 and 8.3.5). By encouraging companies to develop and supply technology and management systems to the commercial sector, the public sector can concentrate its limited resources on research to produce public goods, the development and supply of technology to the poor and the development and diffusion of environmental and health services.

It appears that the underinvestment in private research in developing countries is even greater than in public sector research. Because of the spillovers of the benefits of technology from private suppliers of technology to farmers and consumers, substantial benefits have accrued to farmers and consumers from private sector research (see 8.2.4 and 8.2.7). The median rate of return to society from research by private firms is 50% (Evenson, 2001). Aggregate studies in India (Evenson et al., 2001) and the US (Huffman and Evenson, 1993) have shown that private research and private imported technology have made major contributions to agricultural productivity growth. Case studies of specific private research programs have shown that the benefits of private research can reach farmers growing poor peoples' crops such as pearl millet and sorghum in rainfed environments such as the semi-arid tropics of India (Pray et al., 1991). Despite these benefits, research investments by the private sector in developing countries lags even farther behind OECD countries than by the public sector investments, both in absolute amounts and in research intensity. Private research investment as a share of Agricultural GDP is 0.03% in developing countries and almost 3% in industrialized countries (see 8.1). To induce more private research, governments can invest in educating scientists and technicians and developing research infrastructure such as ex situ and in situ germplasm collections and basic research programs such as enhancing the diversity of plant and animal germplasm, which will generate ideas for new technology in the private sector. It also requires an enabling business environment for private investment (see 8.1). The components of an enabling business environment include a system for protecting intellectual property rights, the ability to enforce contracts, a stable regulatory environment, functioning markets for agricultural inputs and outputs, and so on. To make sure that private investments in AKST meet societies' goals, governments need to put in place incentives that will induce private firms to meet social goals. These incentives can be positive such as payments for environmental services that could induce firms to develop technology to more effectively provide those services. These incentives can also be negative, for example environmental and food safety regulations and liability laws that penalize negative externalities from introduced technologies. In addition, industrial policies that limit monopoly power will also be needed. Government alone cannot enforce regulations and industrial policies. The active involvement of NGOs and other parts of civil society is essential.

Tradeoffs occur between different development goals when different choices of AKST investments on specific commodities or types of institutions are made (Table 8.20). For example, RORs to wheat research have been high (see 8.2.4), but the research that produced high-yielding wheat varieties may also have induced more irrigation of wheat in poorly drained regions, which has led to increased salinity, destroyed land, and displaced farmers. Pesticide use on wheat is limited so there has been little negative impact of pesticides. Green revolution wheat varieties reduced prices of wheat, which increased consumption of wheat by the poor improving their health. The high yielding wheat varieties during the green revolution period in South Asia increased demand for labor and thus the incomes of the poor (Lipton, 2001). An example of research that has positive effects on economically sustainable development, but a negative impact on other development goals is research to increase the productivity of intensive livestock production. It has high RORs but major negative environmental effects through water and air pollution, and negative health impacts through *E. coli* and other public health crises (see 8.2.5 and 8.2.6). At the same time it can have positive health impacts through dramatic declines in the price of meat and poultry, which in turn facilitates access for more people to animal protein and other essential nutrients.

[Insert Table 8.20]

8.4.2.1. Options for societies aiming to give major support to environmental sustainability

For these societies investment in AKST can have three different, but complementary, alternatives: reducing the negative environmental impacts of farming systems, enhancing existing agricultural systems that have been shown to be environmentally sustainable, and developing new agricultural systems. They will have to focus on providing ecosystem services such as reduced greenhouse gas emissions, absorption of the carbon dioxide, reduced water pollution and slowing the loss of biodiversity.

We have made judgments about the most important negative impacts of agricultural technologies on the environment (see 8.2.5); unfortunately, data is not available to know which of the impacts are most important or which negative impacts could be mitigated most effectively through investments in AKST. This gap suggests that 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 farming systems from a monetary perspective as well as from other perspectives such as the concept of energy flows used in ‘emergy’ evaluations. Evidence on these externalities’ potential implications on food security also needs to be analysed.

There are three other types of AKST investments in which countries can invest. First is research to develop management practices, technologies, and policies that reduce the ecological footprint of agriculture, such as reducing agriculture’s use of fossil fuels, pesticides and fertilizers. This would include AKST investments to develop management practices such as: no-tillage systems to reduce use of fossil fuels for tillage, integrated pest management strategies to avoid overuse of inorganic pesticides, integrated soil management technologies to reduce the need for inorganic fertilizer, rotational grazing and support of mixed farming systems to improve the nutrient cycling within agriculture and livestock production. In this area, investments on sustainable and low-input farming practices would also be recommended. AKST investments can also increase agriculture’s role as a carbon sink. The greatest dividends would come from conversion from grain crops to agroforestry as there is a benefit from both increased soil organic matter and the accumulation of above-ground woody biomass. Thus, agroforestry can play a major role in the two key dimensions of climate change: mitigation of greenhouse gas emissions and adaptation to changing environmental conditions (Garrity, 2004). Other management strategies such as including grasslands within rotations, zero-tillage (or no-till) farming, green manures, and high amendments of straw and manures, would also lead to substantial carbon sequestration (Pretty and Ball, 2001).

A second type of AKST activity would be the development of biological substitutes for industrial chemicals or fossil fuels. These would include new biopesticides, improvements in biological nitrogen fixation, and search for alternative sources of energy that do not compete with food production and do not induce deforestation. There is some evidence that research in this area can provide a good economic ROR, and the RORs are likely to rise as more governments put policies in place that reward farmers for the provision of these services.

Third, research to support traditional knowledge on effective ways of using and conserving available resources such as soils, water, and biodiversity to improve rural livelihoods will be required. This knowledge has been neglected but research and management systems based on this knowledge have been shown to have positive ecological and economical impacts in all areas of agriculture (crops, livestock, aquaculture and agroforestry). New nonconventional crops and breeds may play a vital role in the future for conserving local and indigenous knowledge systems and culture, as they have a high local knowledge base which is being promoted through participatory domestication processes (Leakey et al., 2003; World Agroforestry Centre, 2005; Garrity, 2006; Tchoundjeu et al., 2006).

This may be an area of AKST that had lower returns to public investments research than some other types of research historically. This is due in part to the difficulty of measuring the impact of research in this area and the lack of studies of the impact of these types of research. It is also partly due to the fact that the complementary policies and institutions needed to implement solutions developed by AKST are often not in place. Considering that agriculture and land use contribute to 32% of global emissions, more research is needed to analyse the potential contribution of new and existing but ignored agricultural technologies and practices that could contribute to decreasing global warming and climate change. Another important type of research investment needed is social science research which develops recommendations for policy and institutional changes that reward farmers for reducing the negative externalities, enhancing the multiple functions of agriculture, and for the provision of ecosystem services. Investments in incentives for private sector to develop technologies that assist farmers to provide ecosystems services are also needed.

For AKST for environmental services to have adequate levels of funding and for the funding to be sustainable, consumers and environmental groups must have a role in the governance of the research system.

8.4.2.2. Options for societies aiming to give major support to improving nutrition and human health

As in the case of the environmental sustainability, this area of AKST investment can adopt several different but complementary goals: to reduce the negative documented impact of agriculture on health and to develop policies and technologies aiming to improve the nutritional and health status of population. The key areas of AKST investment could be in improved quantity and nutritional quality of culturally appropriate food to the poor, safer management or reduction in use of pesticides and research to improve food safety. This is another area for which evidence is lacking and where investments are needed to obtain data on the size of the problem and the potential of AKST to solve it.

AKST has positive and negative effects on human health (see 8.2.6). Increased plant and animal productivity have reduced prices of these food products and often reduced under-nutrition of the poor and led to more balanced diets. At the same time, increased productivity has led to environmental pollution (of water and air) and overuse of antibiotics and pesticides (including toxic residues in plants and animals and resistance to antibiotics) have lead to serious health impacts. Additionally, problems of growing obesity in industrialized and developing countries are also indirectly linked to AKST.

The evidence on negative impacts suggests that one area of major AKST investment needs to be on improved pesticide management and the reduction in use of dangerous pesticides and antibiotics (see 8.2.6). In particular investments in IPM and substituting less dangerous chemicals or biopesticides for dangerous pesticides appear to be important investments. Farming systems which improve productivity while using little or no pesticide, chemical fertilizer and antibiotics need to be studied and developed in order to improve their management and increase their potential to feed the local population. Organic agriculture is one type of farming system that reduces pesticide use and has a growing demand, so investments in research to increase the productivity and resilience of organic agriculture would be appropriate.

AKST investment to develop and implement schemes for food safety and quality standards to improve public health and consumer confidence is a major area in the health portfolio. In addition, investments to increase the nutritional values of crops and livestock products with the objective of improving the nutritional status of global population, such as biofortification, need more emphasis in plant breeding research. Biofortification is one of the few areas where there have been careful studies both of the size of the health problem and that AKST investments can reduce these problems (see 8.2.6).

Farming system diversification can also improve nutrition. The expansion of vegetable and fruit tree cultivation on farms can have a significant effect on the quality of child nutrition. Many indigenous fruits, nuts and vegetables are highly nutritious (Leakey, 1999b). The consumption of some traditional foods can also help to boost immune systems, making these foods beneficial against diseases, including HIV-AIDS (Barany et al., 2003; Villarreal et al., 2006). If countries neglect investments to improve the farming systems of both subsistence and commercial farmers, major health problems would increase.

Reduction of nutritional imbalances would require research on educational programs and policy mechanisms to provide appropriate incentives for facilitating the access to healthier products and healthier consumption patterns while penalizing in the market those products leading to nutritional problems, for example, through the internalization in the final price of the products the health costs calculated by means of AKST. Still, more AKST from social sciences is needed in order to find and develop the best policy strategies to avoid malnutrition. The AKST investments to continue the reduction in the numbers of the undernourished through productivity increasing research or better distributional or commercialization strategies of food are described in more detail below in the section on poverty.

8.4.2.3. Options for societies aiming to give major support to hunger and poverty reduction

These societies will need to target investments in research, policy and institutional change in organizations that provide research to produce public goods. These include public research, extension and education programs as well as the international research centers of the CGIAR.

AKST investments can increase the productivity of major subsistence crops such as rice, wheat, and other basic staples that are grown and/or consumed by the poor (see 8.4.3.1) while respecting the culture and livelihoods of those who produce the food. Investment can also be allocated to the productivity-increasing research in regions where the poor are located, such as rain-fed and marginal areas, even if these are not the areas which would increase total Agricultural GDP the most. Also, investments to preserve biodiversity and traditional systems that maintain the livelihoods of millions of people are required in order to increase the wealth of poor populations in many countries. For example, research on animal genetic resources conservation programs could be directed to increase drought resistance or disease resistance of local domestic breeds. This implies appropriate technologies that do not destroy the environment while at the same time aims to improve the existing local knowledge of traditional farming systems towards the needs of the farmers.

Research for the poor should aim to develop and maintain crop and animal production techniques that allow extending the assets controlled by the poor such as labor, management skills, or biodiversity with assets owned by the wealthy, such as land.

Investments in institutional change and policies which improve the access of the poor to food, education, land, water, seeds, markets and improved technology for producing food, better access to jobs, and more influence on the governance of research systems are a major need for reducing poverty (see 8.3.4). The investments in improved institutions might include AKST programs that support small scale agricultural and food industry innovators and public private partnership with the aim to (i) encourage adaptation and adoption of pro-poor technologies from the public research agencies, (ii) adapt scientific discoveries from industrialized countries and, if needed, import technology from them that increases the productivity of poor farmers; and (iii) transfer technology from neighboring countries, which may have developed technology that is more appropriate for poor farmers in developing countries than those of industrialized countries. These technologies can flow through multinational corporations, local private firms, public sector research systems and their regional networks, and farmer-to-farmer communication.

8.4.2.4. Options for societies aiming to give major support to economically sustainable development

These societies should consider investing in AKST which provides evidence of high future (ex ante) RORs. These investments will include some areas that had high ROR in the past such as yield increasing technologies and promise high returns in the future since there will be continued demand for these technologies and science. AKST investments in water management and pest and disease management, which have less history of high returns but are likely to have high returns in the future because of high demand or recent advances in science, would also be included. In addition, some AKST investments that did not have high returns in the past, such as NRM, are likely to have high ROR in the future if policies, such as carbon trading under the Kyoto protocol or subsidies for good environmental practices in agricultural policies, provide incentives to adopt these technologies. It is clear that economically sustainable development can only be achieved if the environment is at the same time preserved

Governments must continue to invest in AKST to develop productivity-increasing technology and management systems that save on the use or reduce the misuse of scarce resources such as land, water, and in fossil fuels. The major resource constraint to increasing agricultural production in the future will continue to be agricultural land. In the future AKST must focus on increasing output per unit of land through technology and management practices. RORs to land saving research are high. There are a limited number of studies which show substantial returns to land management research. However, future AKST must avoid the negative externalities of past investments in this area.

Water is the next most important resource constraint to agricultural production and is likely to be even more of a constraint in the next 50 years. AKST resources are being reallocated into water-saving techniques, improved policies and management techniques. The expected ROR to investments in water productivity research may be lower than for germplasm research. Nevertheless, comparing the cost of science-based studies with the costs of inaction (growing poverty, malnutrition and disaster relief) indicates that the benefits of science-based actions vastly exceed the costs (Kijne and Bennet, 2004). Still, a few examples of water-saving research, which were evaluated by SPIA had high returns (Zilberman and Waibel, 2006), and some of the research on drought tolerant crops (both breeding new varieties and recovering existing ones) looks very promising. However, the development of these technologies will take time, and major changes in water pricing policies are likely to be needed to give farmers in irrigated areas incentives to adopt such technologies.

Fossil fuels in the long run may run out. Concerns about their impact on global warming, and the high price of fossil fuel has once again focused attention on the need for agriculture to save on the use of this scarce resource and support agricultural systems that have higher outputs per unit of sustainable energy. In this context, low-external-input agriculture could bring promising opportunities. There is little evidence yet from the ROR literature of high returns, but the demand is there and agricultural research has the capacity to produce appropriate technologies (see also chapter 6). Since prices are likely to continue to fluctuate due to politics as much as to scarcity, AKST investments by governments will be necessary to develop these technologies and to inform farmers how they may best reduce agricultural use of fossil fuels.

Major public and private R&D investments will be needed in emerging issues such as plant and animal pest and disease control. Continued intensification of agricultural production, changes in agriculture due to global warming, the development of pests and diseases that are resistant to current methods of controlling them, or changes in demand for agricultural products such as the increasing demand for organic products, will lead to new challenges for farmers and the research system Investments in this area by the public and private sector have provided high returns in the past and are likely to provide even higher returns in the future. In addition, these investments could lead to less environmental degradation by reducing the use of older pesticides and improving livestock production methods. These technologies could also use more labor, which in labor abundant countries, could reduce poverty. They would also positively impact human health. Pest and disease control is an area in which public and private collaboration is essential.

Pre-invention, strategic, and basic research can be justified in many countries and in international research centers. The studies that try to estimate the separate impacts of different components of AKST find that both applied and more basic research investments have high returns (see 8.2.4). Advances in basic biological knowledge such as genomics and proteomics, nanotechnology, ICT, and other new advances in AKST will create major new opportunities for meeting development and sustainability goals (see chapter 6). Emerging knowledge of agroecological processes and synergies, and the application of resultant technologies, will play a crucial role in future AKST investments. Both new and existing but neglected knowledge can pay off by increasing public and private development of technologies and management practices that improve agricultural production, mitigate climate change, improve health or reduce poverty. Thus, it is not inherently productivity increasing or polluting but is needed to achieve economically sustainable development. A major increase in private sector research will be needed to increase agricultural productivity growth for developing countries.

8.4.2.5 A portfolio of AKST investments to meet multiple goals

If, as has been argued earlier in this sub-chapter, a large infusion of public funding in AKST is needed, a coalition of interest groups will have to lobby for this increased funding. This suggests that policy makers and advocates for AKST activities that increase environmental sustainability, achieve economically sustainable development, improve nutrition and health, and reduce poverty, should attempt to put together an AKST investment portfolio that attracts groups beyond the traditional agricultural community. The investment areas listed above which can meet multiple criteria could be attractive to these different groups. As indicated above, many AKST investments can meet multiple goals. Other investments primarily meet one goal but still play a valuable role and should not be eliminated because they do not make major contributions to all of the goals. For example, private research to increase poultry productivity may create increased pollution, but this does not mean that governments should try to prevent private poultry research. A more appropriate approach may be to encourage the private sector to do productivity-enhancing research but at the same time prevent the potential pollution through more effective enforcement of laws against pollution, by mandating waste management plans or by public sector research to development management systems which reduce pollution and improved public health.

One strategy is to make small public investments in an enabling policy environmental that would encourage private research and shift public research into the production of public goods and meeting other social goals such as improving the environment or developing technology for resource poor farmers or into basic research. For example, many countries could reduce their public research investments on improving the productivity hybrid maize, which will be done by the private sector, and shift those resources into productivity-enhancing research on cassava or open pollinated varieties of maize grown by poor people. Or the resources could be shifted into fertilizer and pest management to reduce overuse of chemicals that create pollution and can harm human health. Shifting more public AKST investments to increase the productivity and adoption of organic agriculture for which markets are available can also reduce the use of nonorganic pesticides and chemical fertilizers.

8.4.3 Future AKST investment levels and priorities

8.4.3.1. Levels of AKST investments

More government funding and better targeted government investments in AKST in developing countries can make major contributions to meeting development goals. The evidence of returns to AKST investments shows that public investments have high payoffs, in the order of 40-50% and can reduce poverty (see 8.2.4 and 8.2.8). These returns are high compared to other public sector investments and evidence shows that AKST investments are one of the most effective ways to reduce poverty. In addition public investments in AKST can be used to reduce agriculture's contribution to global warming and to improve public health. However, to do this public investments must be targeted using evidence other than the ROR, which usually do not include environmental and human health impacts, positive or negative, or the distribution of costs and benefits among different groups.

Increasing investments in agricultural research, innovation, and diffusion of technology by for-profit firms can also make major contributions to meeting development and sustainability goals. Private firms both large and small have been and in the future will continue to be major suppliers of inputs and innovations to both commercial and subsistence farmers. They will not provide public goods or supply good and services for which there is no market, but evidence shows that there are spillovers from private suppliers of technology to farmers and consumers.. However, private research intensity in developing countries is only one hundredth of the corresponding ratio in industrialized countries. To make the best use of private investments in AKST, governments must provide both government regulations to guard against negative externalities and monopolistic behavior and support good environmental practices providing firms with incentives to invest in AKST.

8.4.3.2 Allocation of AKST resources

Social science research to assist priority-setting, to measure the impact of past AKST investments in health and the environment, to improve AKST and complementary institutions and policies, and to link with indigenous knowledge is a high priority investment**.** One of the major constraints of this assessment is the lack of evidence on both the positive and negative impact of AKST on the environment, human health, and, to a lesser extent, on poverty reduction (see 8.2.5, 8.2.6, 8.2.8). Investments are needed to develop better methodologies and indicators to measure these impacts, both with monetary and nonmonetary values. In addition, investments are needed to develop better methods for measuring the contributions of indigenous knowledge, social science research on institutions and policies, the value of improving governance systems, and better priority-setting tools and methods. Finally more investments are needed in research priority setting processes in developing countries which include both social and natural scientists and input from stakeholders (see 8.4.1).

AKST investments that can increase the productivity of agriculture and improve the existing traditional systems of agriculture and aquaculture in order to conserve scarce resources such as land, water and biodiversity remains a high priority. The major resource constraint on increasing agricultural production in the future will continue to be agricultural land. AKST must focus on increasing output per unit of land through technology and management practices. Water is the next most important resource constraint to agricultural production and is likely to be even more of a constraint in the next 50 years. AKST resources need to be reallocated into water-saving techniques, improved policies and management techniques. Fossil fuels in the long run will run out and recently high prices due to political conflicts have once again focused attention on the need for agriculture to save on the use of this scarce resource. Since prices are likely to continue to fluctuate with politics as much as on scarcity or their negative externalities, government investments in AKST will be necessary to reduce agricultural use of this resource.

AKST investment to reduce greenhouse gas emissions and provide other ecosystem services is another priority investment area. Agriculture and land use contribute 32% of total GHG emissions (Stern, 2007). Thus, AKST investments to develop policies, technologies and management strategies that reduce agriculture’s contribution could facilitate to decreasing global warming. This requires the development of new farming systems, which use fewer technologies, produces less GHG, and builds on indigenous knowledge to improve current cropping systems to be more sustainable. These systems could include practices such as no-tillage systems, integrated pest management strategies, integrated soil management technologies, rotational grazing and support of mixed farming systems to improve the nutrient cycling. A second, complementary type of AKST activity is the development of policies such as payments for environmental services from farmers, which could induce the development and adoption of practices that provide environmental services. In addition, some of the agricultural technologies and policies for provide these ecosystem services can be designed to use the assets of the poor, such as labor in labor-abundant economies which would reduce poverty.

Major public and private research and development investments will be needed in plant and animal pest and disease control. Continued intensification of agricultural production, changes in agriculture due to global warming, the development of pests and diseases that are resistant to current methods of controlling them, and changes in demand for agricultural products, will lead to new challenges for farmers and the research system. Investments in this area by the public and private sector have provided high returns in the past and are likely to provide even higher returns in the future. In addition, these investments could lead to: less environmental degradation by reducing the use of older pesticides and livestock production methods; more labor use, which could reduce poverty; and positively improve human health of farmers and their families by reducing their exposure to pesticides. This is an area in which public and private collaboration is essential.