IAASTD GLOBAL REPORT CHAPTER 9

AGRICULTURAL KNOWLEDGE, SCIENCE AND TECHNOLGY: INVESTMENT AND ECONOMIC RETURNS

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Key Messages

On average investments in AKST is 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 agricultural public AKST in many developed countries has stalled or declined and has become a small proportion in total S&T spending. Many developing countries are also stagnating or slipping in terms of public AKST investments. However, a selected few, often the more industrialized countries, have substantially increased their investments. The slowing growth in AKST investments in the public sector is likely to have implications for attaining the development goals.

Funding for public AKST 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 AKST specifically, government remains the major source of funding for public AKST in most developing countries. The trend indicates that donor support for AKST has substantially declined since the mid-1980s with the majority of this smaller amount supporting global research rather than research at the country level.

The participation of non-governmental agencies in AKST 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 AKST. Still, publicly funded research in developing countries is mostly conducted by government-sponsored agencies.

There is evidence of under-investment in research in agriculture. Rates of Return (ROR) in AKST across commodities, countries and regions on average is high and has not declined over time. They are much 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 agriculture R&D perform equally well or better than the other public-sector investments in the agricultural sector.

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 ownership of 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 ownership patterns.

RoR alone is insufficient 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 non-economic positive impacts are also highly valued by 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 sectors such as forestry and fisheries as well as policy-oriented social science research.

The level, effectiveness and efficiency of AKST investments and their contribution to broader development goals vary according to governance. Governance is an important determinant of mobilization of resources for AKST and plays a major role in allocation of resources between different components of AKST. Governance also is very important in determining the nature and incentives in AKST institutions, which have implications for efficiency, effectiveness and equity of AKST investments.

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.

Increasing participation of non-governmental stakeholders in decision making is improving the governance of AKST systems. Increased participation of farmers, producer associations, and private sector has shown signs of improving the performance of AKST, which in the past was often captured by urban and rural elites.. The role of this broader spectrum of actors in governance forces AKST institutions to develop and disseminate technologies that meet the needs of a broader section of rural society than in the past. Governments continue to play an important role in providing public goods, assuring equitable access to AKST, and creating an enabling policy and institutional environment.

International support or mediation of AKST can sometimes distort the incentives in national or local research systems. Such distortions include the laxity it creates among the national players in the mobilization of resources, distortions in research priorities, in resource allocation between different expenditure items and in improper risk assessment of research projects. However, international interventions driven by the considerations of global public goods and trade, political and altruistic reasons will continue to play an important role in future. Thus international actors need to be sensitive to the possible distortions that they can create in domestic institutions and incentives.

Political economy (the conflicts between and influence exerted by different social groups) affects the way the governance decisions on AKST are made. This sometimes results in the neglect of the requirements of the poor, women and other marginalized groups who do not have the necessary income, resources, and political clout. Political choices based on economic power can be a source of ineffectiveness, inefficiency and ultimately non-achievement of development goals. Even when decisions are made expressly to help these groups, the real benefits may accrue more to the influential groups within society.

More investment in public research is necessary to reach the IAASTD goals of sustainable economic development and enhanced livelihoods and equity. Developing countries need to increase research intensity levels towards the levels of OECD countries. This would involve major investments by both the public and private sectors, which is justified given the high rates of return to research found in thousands of studies. Even if this level of investment was not economically profitable and it lead to a decline in the narrowly defined economic RoRs, the extra investment should be done because of the social and ecological benefits that this extra investment could achieve.

To meet poverty reduction goals an important share of AKST investment should be focused on the problems of the poor. Productivity increasing research that is to be pro-poor should focus on major subsistence crops that make up a major component of expenditures of the poor. AKST should focus on regions where the poor live, and problems that often particularly are a problem for the poor, such drought or marginal lands. AKST should also focus resources on income-generating opportunities for the poor that can help them generate income so that they can move out of poverty. The rate of return studies have shown that, even in poor countries and regions and for research on subsistence crops, the rates of return are high. The governance sub-chapter suggests that these investments will be particularly high when the poor themselves have a say in how these resources are allocated. But for the poor, change is required to correct past distortions that have worked against their interests, amounting to corrections of both problems of under- and mis-investment.

More AKST resource must be invested developing technology and management systems that save on the use of scarce resources such as land, water, and in the future, fossil fuels. The major resource constraint on increasing agricultural production in the future will continue to be agricultural land. Governments, international organizations and private firms have responded by developing more intensive agriculture and in the future 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 are starting 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.

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 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 livestock production methods; more labor use, which could reduce poverty; and positively improve human health. This is an area in which public and private collaboration is essential

Recognizing the multifunctionality of agriculture necessarily leads to more public investment in AKST to help agriculture provide ecosystem services such as reduced greenhouse gas emissions, reduced water pollution, and slowing the loss of biodiversity and maintenance of livelihoods. These investments will be of three types. First, research to develop management practices, technologies, and policies that reduce the ecological footprint of agriculture, such as reducing agricultures' use of fossil fuels, pesticides, and fertilizer. This would include AKST 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. 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 biological nitrogen fixation, and ethanol from sources such as sugarcane or biomass that do not compete strongly with food production. There is some evidence that research in this area can provide a good economic rate of return, and the rates of return are likely to rise as more governments put policies in place that reward farmers for the provision of these services. Third, research to support indigenous knowledge to improve rural livelihoods will be required. This knowledge has been neglected but research and management systems based on this knowledge has been shown to have positive ecological and economical impacts. In addition, some of the agricultural technologies to provide these ecosystem services can be designed to use the assets of the poor, such as labor in labor-abundant economies.

Investments in the governance of AKST and on research to better understand the role of governance are needed. If the goal of research investment is to make AKST more inclusive, accountable, and transparent, guided by an awareness of ecosystems services, poverty, and health issues, money will be needed to create the appropriate institutional changes. As in the recent past, pressure for institutional change must come from interest groups that truly represent agricultural interests, but once that pressure comes forward, resources are going to be needed to make worthy changes. In addition, research in the social sciences to better understand what type of governance will make AKST most effective at procuring financing, most efficient at conducting research, and most responsive to the needs of farmers and consumers is also likely to have high payoffs.

Multi-criteria decision-making processes that make more systematic use of economic RoRs, measures of ecosystem services, poverty, health, and risk are needed. More systematic decision making could improve the efficiency of research since little use is currently made of formal priority setting tools now in in developing countries. Explicitly using information on the potential impact of AKST on ecosystem services, poverty reduction, and improved health in research resource allocation would also generate more support for government expenditures on agricultural research from environmental, health, and anti-poverty groups. However, these impacts are difficult to calculate, and especially to value in monetary terms. There have been only a limited number of studies that have documented these impacts of research. Thus, it is still difficult to put multi-criteria decision-making processes into practice. There is clearly a need for more research that documents the limitations and potentials for different types of AKST investments to provide ecosystem services, to alleviate poverty and to improve health.

9.1 Investment and funding trends in AKST

9.1.1. Trends in agricultural R&D investments

Public research. Worldwide, public investments in agricultural research and development (R&D) increased, inflation-adjusted terms, over the past two decades from an estimated $15.3 billion in 1981 to $23.0 billion in 2000 (in 2000 international dollars) (see Box 9.1); an increase of about one half (Table 9.1).[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 developed world. Investments by Asia and Pacific countries as a group grew relatively resulting in a 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 1990s. In contrast, the corresponding share for sub-Saharan Africa continued to decline, falling from an 8 to a 6% share 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, just two countries—United States and Japan—accounted for 54% of public spending in 2000; about the same 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.

Insert Table 9.1. Total public agricultural research expenditures by region, 1981, 1991, and 2000

Growth in inflation-adjusted spending has slowed down since the 1970s when most regions experienced high growth rates (Figure 9.1). 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 new government policies to revitalize public agricultural research and improve its commercialization prospects. Two large regions, Latin America and the Caribbean, and West Asia and North Africa, both experienced relative less growth in total spending (2.0 and 3.3%, respectively). In contrast compared to a decade earlier, the increase in total spending in Sub-Saharan Africa decreased in the 1990s from 1.3% to 0.8. An even more severe drop in spending is found in many countries. In about half of the 27 countries for which time series data were available, the public sector spent less on agricultural R&D in 2000 than 10 years earlier (Table 9.2).

Insert Table 9.2. Variation in annual growth rates in total spending in 27 sub-Saharan African countries, 1991-2000

Insert BOX 9.1. Investments in international versus U.S. dollars

Insert Figure 9.1: Growth rates of public agricultural R&D spending

Noteworthy is the decline in total 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. Pardey et al. (2006b) state that these slowdowns in agricultural R&D spending will curtail the future spillovers of technologies from rich to poor countries.

Orientation by commodity groupings. The allocation of resources among various lines of research is a significant policy decision and take place at different levels and, in theory (although not always in practice), follow the priorities set across commodity and multi-disciplinary research programs. More than one half of the fte researchers in a sample of 45 developing countries conducted crops research while 15% focused on livestock and 8% on natural resources research (Table 10.3). Noteworthy, Asia-Pacific had relatively less livestock researchers (13%) than sub-Saharan Africa and Latin America (18% each). Forestry, fisheries, and post-harvest 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. The major crops being researched in fruits and vegetables in all three regions. Unsurprisingly, rice is a relative important crop in the Asia-Pacific region while maize has high importance in Latin America.

Insert Table 9.3. Commodity focus by main research area , various years

The allocation of AKST resources above do not cover the full scope of AKST, areas which importance will be eminent in the future such as bioenergy, climate change, and transgenetics, [**other?**]. The influential, although also criticized, Stern Review on the Economics of Climate Change (Stern 2006) 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 but most agree that the Economist argue whether the figures in Stern's review are right but 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. Amongst these could be the creation of incentives for investment in low-carbon technologies. However, Information on the S&T investment levels that are already available and/or will be needed in the future for the adaptation of climate change are unavailable.

Information on the investment levels in bioenergy research are seemingly unavailable, although there is considerable evidence that overall energy R&D investments in developed countries have declined, despite the need for an increase in energy-saving technologies to battle global warming (Dooley and Runic, 1999; Nemet and Kammen, 2007; Revkin 2006). [**continue to look for references?]**.

Institutional orientation. 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 9.2). Public research in the United States is done mainly in state agricultural experiment stations (SAES) located principally in colleges of agriculture and in federally administered, but often regionally located, laboratories of the United States Department of Agriculture (USDA). The SAES share of total USDA-SAES research has increased over the past several decades, from 67% in 1980 to 74% in 2004. A large share of public agricultural R&D in Latin America is conducted by government agencies—about 74% of the total in 1996 (the latest year for which data were available). This is similar to the government agency share in a 27-country Sub-Saharan African total. Like Latin America, a small but growing proportion of public research in Sub-Saharan African is conducted by nonprofit institutions; in 2000, for example, they accounted for 3% of total agricultural research staff. 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. Examples include agencies conducting research on tea (Kenya, Tanzania, Malawi), coffee (Uganda, Kenya, Tanzania), cotton (Zambia), and sugar (Mauritius, South Africa). Noteworthy is the establishment of various other forms of nonprofit institutions, not linked to producer organizations, in a number of countries, such as Madagascar and Togo.

Insert Figure 9.2: Institutional orientation of public agricultural R&D, 1981, 1991, 2000

Private-sector spending. Agricultural R&D investments by the private sector have grown in recent years and in the developed 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, but most of these technologies are produced in the developed world (see Box 9.2).

Insert Box 9.2: Plant breeding and biotechnology research

Pardey et al. (2006a) estimated that the private share of total agricultural research is 37% (Table 9.4). Most of this private-sector performed research was done in the rich countries (94%) where the private sector 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 relative higher in the Asia and Pacific region with an average of 11% in 2000.

Insert Table 9.4. Estimated public and private agricultural R&D investments, 2000

Private sector involvement in agricultural R&D 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 one quarter in Australia, Austria, Iceland, and Portugal that same year. Private and public sector are involved in different type of research. In 1993 only 12% of the private research in five developed countries (Australia, the Netherlands, New Zealand, United Kingdom, and the United States) focused on farm-oriented technologies compared to 80% in the public sector. Food and other post-harvest 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 United Kingdom and United States of America, was less important in Australia, and almost negligent in New Zealand (Alston et al. 1999).

A survey of seven Asian countries by Pray and Fuglie (2001) 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. But this growth was uneven across subsectors. Total investments in the agricultural chemical industry in Asia, which include mostly pest control chemicals and, in a lesser extent, fertilizer and biotechnology, tripled during mid-

1980s and mid-1990s. Private spending on livestock research also grew considerably, but growth was substantial slower in other subsectors such as plantation crops and machinery. Pray and Fuglie (2001) also found that 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 was done by multinationals. Noteworthy is that foreign firms were concentrated in the agricultural chemical and livestock subsectors; those with the highest growth.

In the sub-Saharan African region, only 2% of total agricultural R&D is conducted by the private sector.[4] Almost two thirds of the region's private research was done in South Africa. Most firms in sub-Saharan Africa are small in number of research staff and total spending and focus crop-improvement research often (but not always) dealing with export crops (Beintema and Stads 2006).[5] Similarly as in the Asian region, multinationals and locally-owned companies play a similar 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. That said, there is substantial potential, perhaps, for tapping into private agricultural R&D done elsewhere—maybe through creative public-private joint venture arrangements (Osgood, 2006).

In 2000, total investments in all the sciences conducted by public and private sector was over $700 billion (in 2000 international prices) (Table 9.5). The regional shares in the global total differ substantially from the shares in agricultural R&D spending. The rich countries combined accounted for about 80% of total science and technology (S&T) spending while sub-Saharan Africa's corresponding share was less than 1%. 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 Sub-Saharan Africa-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 developed world spending in agricultural R&D was only 4% of the total S&T investments.

Insert Table 9.5: Total S&T spending by region and shares agriculture in total, 2000

Intensity of research. Analyzing absolute levels of research expenditures and number of researchers explains only so much. In order to place a country's agricultural R&D efforts in an internationally comparable context, one other way is to measure the intensity of investments in agricultural research. The most common research intensity indicator is to measure total public agricultural R&D spending as a percentage of agricultural output (AgGDP).[6] The developed countries as a group spent $2.36 on public agricultural R&D for every $100 of agricultural output in 2000, a sizable increase over the $1.41 they spent per $100 of output two decades earlier, but notably, slightly down from the 1991 estimate of $2.38 (Figure 9.3). This longer-run rise in research intensity starkly contrasts with the group of developing countries where there has been 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 group than in the developed countries. As a result, intensity ratios remained fairly stable for the developing regions as group despite overall higher growth rates in agricultural R&D spending in the developing countries, and the intensity gap between rich and poor countries have widen over the years. Furthermore, more than half of the developed countries for which we have data 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 period. But only 6 of the 26 sub-Saharan countries in our sample had higher intensity in 2000 compared to two decades earlier.

Insert Figure 9.3: Intensity of public agricultural R&D investments

The aforementioned large and growing gap between developing and developed countries as groups is even larger in terms of total—that is public and private—agricultural research spending (Figure 9.4). In 2000, the intensity of total spending was nine times higher in rich countries than they were in poor ones; four times higher when only public research spending was used as the basis of the intensity calculation.

Insert Figure 9.4: Public, private and total agricultural research intensities, 2000

Other research intensity ratios can be calculated as well. The developed countries as a group spent $692 on public agricultural research per agricultural worker in 2000, more than double the corresponding 1981 ratio (Table 9.6). 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 taking into account the fact that a much smaller share of the workforce in the developed world 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 developed 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; most severely Japan 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; whereas 59% of the developed countries invested more than $10 per capita in 2000. But 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 Sub-Saharan Africa where spending per capita has declined during the 1981-2000 period.

Insert Table 9.6. Other intensity ratios, 1981, 1991 and 2000

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 various international institutions such as the International Rice Research Institute (IRRI) in the Philippines in 1960 and the International Maize and Wheat Improvement Center (CIMMYT) in Mexico in 1967. Various other centers were established beginning with the International Institute of Tropical Agriculture in Nigeria in 1967 and the International Center for Tropical Agriculture in Colombia in 1968. These centers became part of the in 1971 established Consultative Group on International Agricultural Research (CGIAR or CG). The number of centers continued to grow over the years to 18 at one point, but some were merged. Currently there exist 15 centers in total, which had a total budget of US$415 million in 2004—US$384 million in 2000 prices (Figure 9.5).

Insert Figure 9.5: CGIAR spending, 1960-2004

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.

After an initial expenditure of US$7 million in 1960, total spending rose to US$13 million per year in 1965. 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 CG system 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. A notable trend has been the declining share of the four founding centers. In 1980, their share in the total CG spending was 54%, but slipped to only 36% in 2004.

9.1.2. Determinants of public and private R&D investments

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

Determinants of public research. The basic justification for government expenditure on agricultural research is that 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. The review of the returns to research in sub-chapter 9.2 will show that public investments have indeed 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 rates of return on other types of government investments are considerably lower than 40% (Alston et al., 2000a; Evenson, 2001), these rates of return to research are very high.

While studies that show high social rates of return to research investments may convince economists that agricultural research is a good investment, most policy makers who actually decide on the allocation of investments do not appear to have been sufficiently convinced that these high social rates of return warrant large investments in research. 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 research 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. In private sector research models this is referred to as an increase in technological opportunity. The discovery of dwarfing genes in rice and wheat, which led to the Green Revolution plant varieties, created the opportunity for plant breeders around the world to produce many new types of varieties that would respond to higher doses of fertilizer and good water conditions. 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 outward 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 (see box 9.2).

Hayami and Ruttan (1985) have also shown that changes in the demand for agricultural products by farmers and consumers induced public investments in research. Historically in Asia, population and per capita income increases shifted up the demand for basic food grains such as rice, farmers were not able to increase production rapidly due to limited land, agricultural prices went up. Private firms did not attempt research to fulfill this demand because there was no way to make sufficient money on selling new rice varieties which could easily be reproduced by farmers to pay for the research. When farmers and/or consumers were sufficiently well organized and demanded a solution, Asian governments invested in agricultural research. For example, the Japanese government just after World War I responded to high rice prices and the demands of consumers in Japan to provide cheaper food and Japanese farmers had run out of land for expansion. The government put money into research that eventually delivered fertilizer responsive rice varieties. Scientists developed this technology that allowed farmers to substitute biological technology and inexpensive fertilizer for land. In the late 1950s, national governments, non-profit foundations, and aid donors responded in a similar manner to the food crisis and high food prices caused by rapid population growth and invested in the international agricultural research centers and the national agricultural research systems. Together these institutions produced the green revolution.

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 those investments. The current worldwide public sector response to Avian Influenza in one example, but new diseases and insects pests are always rising to create demand by farmers for action from the public sector. But there are also demands that do not receive sufficient investments needed for large numbers of the (poor) population such as research in diseases as malaria or the investment in appropriate technologies in agriculture for the poor.

Whether these factors will actually lead to more or less research investments by governments will be determined by the structure of the government, the government's ability to raise money (its budget), and the power of various interest groups to influence government spending.

Some governments are more committed to R&D as a major tool for economic development. They will put a larger share of their budget into research of all types including agriculture. The structure of the research system will also influence the size and direction of agricultural research. 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 themselves, 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 research. For example, if commercial farmers are politically powerful, they can push their governments for large investments in agricultural research and that research is likely to concentrate on reducing the costs of producing their crops or increasing the demand for these crops. 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 which will make private research more productive.

Determinants of private research. For private firms agricultural research is an investment that they hope will increase their profits. If not, they will not continue to invest in research for very long. Profitability of agricultural R&D investments is determined by the costs and returns to the research investments, which are in turn influenced by several factors.[7] 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. The profitability of private research also depends on technological opportunities.
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 agro-climatic 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. Further, 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. 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 by farmers. Finally, bilateral and multilateral trade agreements reshape trading rules and influence market access and thus potential market size.

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. 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, 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.

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.

In summary, 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.

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 that these inputs will have to be employed to develop a new technology, and the stock of knowledge in this 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 cost of conducting research for those who do not have access to such technologies will increase.

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 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 research costs and the 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 excessive product testing regulations and seed certification procedures can greatly increase the costs of commercializing research output. 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, seed companies have spent US$1.6 to 1.8 million to obtain regulatory approval for Bt cotton in India (Pray et al. 2005). In the US the average cost for complying with the regulatory requirement for a single GM product is US$5–6 million (Kalaitzandonakes and Alston 2006). 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.

9.1.3. Investments in other AKST components

Investment data for the other AKTS components are difficult to obtain. We found it impossible to quantify global investments involved in educational efforts (much lower than those for research), or the creation of indigenous knowledge due to a lack of robust data, but it doubtless represents a small fraction of the resources going to mainstream research (perhaps of the order of less than 5%). Relatively more data are, however, available on extension, especially personnel numbers, so estimates of investment can be made.

The services provided by extension have significant public-good attributes. It is, therefore, not surprising that the great majority of official extension workers worldwide are publicly-funded and delivered by civil servants. Universities, autonomous public organizations, and non-government organizations (NGOs) deliver perhaps 10% of extension services, and the private sector may deliver another 5%.

According to Anderson and Feder (2007) there continues to be of the order of 0.75 million agricultural extension workers worldwide, but 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). The investment picture of the partition between public and private is surely changing but remains to be studied in quantitative terms.

Public extension systems in some European countries have been substantially down-sized or phased out altogether, reflecting a policy shifting to environmental rather than agricultural management issues. In both North American and Western Europe, technical support to farmers is largely being provided by highly qualified agricultural specialists who work for private sector firms, especially input supply companies. At the same time, some Eastern European countries, such as Poland and Hungary, still have large public agricultural extension systems. Some other European (but not Nordic) and Commonwealth of Independent States countries are attempting to privatize their extension systems, with mixed results. In general, farmers are unwilling to pay for agricultural extension services on a continuing basis unless these services are integrated with the sale of inputs or with other technical and/or marketing services.

The number of extension workers in most developing countries appears to be stable in terms of total numbers, but these systems are also being transformed to improve their effectiveness and cost efficiency (World Bank 2006). In 2006, for example, China continues to have the largest extension system in the world (371,350 extension workers in crop-related extension and with a comparable number in livestock extension), but has rapidly moved to shift the cost of extension to farmers. It now recovers most of the cost of extension through the sale of inputs and services to farmers at the county and township levels. India, which has the second largest number of extension workers in the world (about 110,000), is undergoing a different type of transformation, including the process of decentralizing its extension system and making it more market driven.

Under this new decentralized extension approach, farmers are beginning to set extension priorities at the district and block-levels but, at the same time, they are being asked to pay for some extension services, particularly those related to the production and marketing of high-value products (Swanson 2006). Less information is available about national extension systems in Africa, the Middle East, Latin America and Southeast Asia but based on current data from selected countries, it appears that the number of extension workers in most countries remains relatively stable. For example, Indonesia continues to have the third largest public extension system, with 30,000 staff members; Iran has 10,500 public extension workers across all subject matter areas; South Africa has 3,000 public extension workers and Tanzania has more than 7,000 public extension workers. Mozambique, on the other hand, has fewer than 2,000 extension staff, nearly one-half of whom are working for NGOs and 228 privately. During the coming decade, it is expected by Swanson that many national extension systems will refocus their efforts toward organizing farmers into groups (building social capital) and then helping these groups increase farm income and contribute to increased rural employment by focusing on high-value commodities and products.

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 as presented in Table 9.1 so it is surprising that it has been subject to relatively little critical data collection and analysis. In contrasting differences between developing and more developed countries, one feature is the even more extreme differentiation between public and private entities; however, as noted in the above discussion of blurring induced by diverse cost-recovery mechanisms, the situation is not fully clear and is surely changing rapidly.

9.1.4. Funding agricultural R&D in the developing world

Although various new funding sources and mechanisms for agricultural research have emerged in recent decades (see a detailed discussion of these in sub-chapter 9.3), 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 [**correct?**], 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. It is therefore appropriate to consider funding trends of agricultural research in relation to the volume of the official development assistance (ODA) from the Development Assistance Committee (DAC) countries to the agricultural sector as well as to national and international R&D investments. 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 9.7). 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 sub-Saharan Africa and decreased by 83% in South and Central Asia during the period 1980-2002 (FAO 2005a).

Insert Table 9.7: Aid to agriculture, 1970–2004

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-developed 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 Latin America and the Caribbean 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 between 1980-2003 although a Department for International Development (DFID) working paper (Morrison et al., 2004) suggests the following contributory factors:

- Loss in donor confidence in agriculture;
- Perceived high transaction costs and complexities in investment in agriculture;
- 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* (see also Eicher 2003).

However, science and the use of new ideas have been acknowledged by many as being important in delivering the Millennium Development Goals (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 sub-Saharan Africa, have become increasingly dependent on donor funding. Although Beintema and Stads (2006) found that the share of donor contributions in total funding for sub-Saharan African agricultural R&D declined slightly in the later half of the 1990s—at least for the 23 African countries in our funding sample (Figure 9.6). 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%).

Insert Figure 9.6. Country-level sources of funding in sub-Saharan Africa, 1995/96 and 2000

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). The CAADP has four priorities (pillars) for investment and actions, one of which involves improving agricultural research improving systems to disseminate appropriate new technologies and increasing support to farmers to adopt these. To achieve the first MDG—eradicate extreme poverty and hunger—the CAADP sets a goal of improving agricultural productivity at an average growth rate of six% each year. To realize this, several African governments have committed to allocating at least 10% of their national budgets to agriculture within five years. In line with CAADP, a study by the Inter-Academy Council (IAC 2004) recommended a doubling of the region's intensity in agricultural research by 2015. Doubling Africa's agricultural research intensity ratio from 0.72% in 2000 to about 1.50% by 2015 as recommended by the IAC study would require an average annual growth rate in agricultural R&D spending of 10%. This goal seems unlikely considering that growth in Africa's R&D spending averaged 1% per year during the 1990s that we reported in the previous sub-chapter of this chapter. There is no evidence that governments and donor organization 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.

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 FAO (2005a) reports that the level of the external assistance to agriculture has remained unchanged. However the situation is continuing to change. As mentioned earlier, the donor community as well as African leaders have recognized the importance of agricultural development to achieving economic growth, poverty reduction and food security.

9.2 Impacts of Investments in AKST

The previous subchapter of this chapter looked at the investment levels into agricultural technologies, but it is also equally important to assess the returns to these investments. What was the impact of investment in agricultural technologies, and who benefited? The development of a meaningful understanding of the impacts of AKST investments needs a conceptual framework. This sub-chapter proposes such a framework, reviews the available evidence on the rates of returns to investments and other impacts and discusses the thorny methodological issues and other constraints to assess the impacts of AKST investments. .

9.2.1. Conceptual framework

In the literature, the term *impact* is used in many different ways. It is sometimes taken to mean any effects that can be attributed to a specified action. In some cases, the concept of impact is used in a restrictive manner and refers only to the long-term outcomes of results of development program on the people, economy, society or environment (Kumar, 1995) or the ultimate effects on the country or organization (DANIDA, 1994). In recent years, the concept has been extended to look at the impact of research on ultimate development goals – food security, protection of the environment and poverty alleviation. Cracknell (1996) and Pingali (2001) illustrated an evolution from the narrow focus in the 1970s and 1980s, an assessment of impacts of germplasm adoption and crop management research, to format rate of return and benefit distribution studies starting in the 1980s. The next broadening of the agenda in the 80s was the work on spill-overs and intersectoral impacts. Finally, the activities have expanded to include gender, environmental, health and poverty impact assessments. SPIA (2001) refers to impact as the broad, long term economic, social and environmental effects resulting from R&D.

Agricultural research generates different outputs including technologies of various types, management tools and practices, information, and improved human resources. Horton (1990) classified technologies broadly into the production technology and R&D technology. *Production technology* refers to all methods that farmers, market agents, and consumers use to cultivate, harvest, store, process, handle, transport and prepare food and industrial crops, livestock or any other enterprises for ultimate consumption. *R&D technology* refers to organizational strategies and methods used by research and extension programs in conducting their work including scientific procedures, institutional strategies, interdisciplinary team research, and so on. The first leads to production impacts whereas the second leads to institutional impact, which refers to the effect of new R&D technology to generate and disseminate new production technologies. R&D technologies are necessary pre-conditions to enhance the development of production technologies.

Impact assessment is a process of measuring whether a research program has produced its intended effects, such as increase in production and/or income and improvement in the sustainability of production systems (Anderson and Herdt, 1990). In any comprehensive impact assessment, it is needed to differentiate between the research results and the contribution of research to development efforts and both aspects should be addressed simultaneously. A framework to assess the various impacts of R&D investment is presented in Figure 9.7. This framework is very much in line with the ecosystem services analytical framework proposed by the MA group. Both frameworks recognize the multiple effects of R&D investments and the need for multicriteria analysis. Any such assessment requires multiple techniques using both qualitative and quantitative assessment. The proposed approach also recognizes that all cost and benefits associated with any R&D investment may not be quantified into monetary terms and converted into a single ROR estimate. Therefore, a multi criteria analysis that included not only economic, but also social and environmental impacts is recommended for assessing the impact. It is important to keep in mind that the economic rate of return is only one aspect of this assessment.

Insert Figure 9.7. Comprehensive impact assessment framework for R&D investment

The purpose of an undertaking impact assessment of agricultural R&D 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 (pro-active) can indicate the potential benefits from research and, therefore, assist the 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. These studies can be carried out to analyze the impact of a particular innovation/technology on a research program, or on a program plus complementary services (such as marketing and extension), or the technology system as a whole. Impact can be measured at the individual household level, target population level, as well as national and sub-regional level (primary sector, secondary sector, or the overall economy).

Most commonly, ex-post impact assessments are carried out because decision makers and research founders 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 R&D investment; (ii) make scientists and researchers aware of the broader implications (or lack thereof) of their research; (iii) Identify weak links in the research – to – impact path ways; and (iv) better inform research managers on the complementarities and trade-offs between different activities within a research program (Maredia et al., 2000).

9.2.2. Economic impact assessment

Economic impact measures economic benefits produced by an R&D 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 R&D program may have other relevant impacts, such as social (poverty, nutrition, gender, and so on) and environmental effects; and benefits of the research may be distributed in different ways. Some non-market impacts such as environmental or health effects of agricultural research 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. Nonetheless, 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.[8] Thus, in any meaningful empirical analysis, a multi-criteria approach is used to asses the impact of R&D assessment.

The literature on economic impact studies includes a wide range of levels of impact analysis. However, since the economic basis for government involvement in agricultural R&D is perception of market failure leading to private underinvestment in R&D (Nelson, 1959; Arrow, 1962; Alston and Pardey, 1998) Alston et al. (2000a) argue that 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 R&D.[9] In a number of studies reported in this chapter, social rate of returns to public investments in agricultural R&D was estimated

The commonly used methods for measuring the ROR to investment in agricultural R&D can be classified into two broad groups. The *econometric approach* estimates the effect of the technology input on output or on the productivity of the sector adopting the technology that is measured. This approach of estimating research productivity is best suited at the very aggregate level of impact analysis and is useful only for ex-post studies. The second group of methods follows the *surplus approach*. The benefits of investment on agricultural R&D are calculated as the net change in producer and consumer surplus, employing a partial equilibrium analysis. The surplus approach measures the average rate of return (ARR) which takes the research expenditure as given and calculates the ROR for the project or program in its entirety. This provides information to assess the success of the project in terms of generating adequate returns. The various types of surplus approach are based on the difference in the assumed nature and elasticity of the supply and demand functions. The economic surplus studies are most suitable at the level of individual research program (Evenson, 1999) and are common in ex-ante economic impact assessment. For standard productivity enhancing innovations, the economic surplus method has proven to be more feasible for computing ROR to research investment than the econometric approach largely due to data limitations in developing countries. However, the ARR measure is not always helpful in determining whether the allocation of research funding to the project was appropriate. They demonstrate how efficient past investments were, but not necessarily where research resources should be allocated in the present, or the future. Furthermore, the approach estimates the ROR for the combined investment making it difficult to separate the contribution of research from other services, such as extension.

As discussed in earlier, the impact of agricultural R&D investments is multi-dimensional. The economic RORs, one of the commonly used measures, in most cases account only for those costs and benefits that could be quantified and measured in monetary terms. It, therefore, does not include the externalities and the non-market effects. Although there have been significant developments in the methodology of estimating ROR, a number of issues still need further attention. Key amongst these are the issues of attribution, incrementality, causality, defining counterfactual situations, and estimating ROR for organizational and institutional innovation and social science and policy research. Furthermore, as public research systems are called increasingly to provide a wider range of benefits, there will be more occasions to incorporate the estimation of non-market benefits into economic as well as social analysis. It is worth noting that some of these issues are inter-related, and adequate attention should be given to these issues in empirical estimation.

9.2.3. Limitations of impact measures

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 R&D investment. R&D programs operate in environments in which ordinary or 'natural' sequences of events influence outcomes. It is important to recognize the distinction between gross outcome' and net outcome of R&D investments. Impact assessment and ROR estimates must arrive at estimates of net intervention effects, i.e. they should measure the incremental changes attributable to the intervention.

Causality is another issue that merits attention. In measuring the impacts of R&D 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).[10] This is further complicated by the time lag between initial investment and reaping its return.

One other difficulty in estimating the ROR is the determination of the contribution of research versus other complementary factors in the outcome measures – the classical attribution problem. 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, of course, 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. Mayne (1999) suggested a number of strategies that can be used to address attribution, called contribution analysis. This may enhance the validity of the estimates, but do not eliminate the attribution issue.

There are some positive and negative effects of agricultural research that are often not counted in ROR estimates In many estimates the spill-over effects are not usually included as benefits. In others, the effects resulting from changes in rural employment, rural health and education policies and programs are excluded. Environmental impacts, both negative and positive, are often ignored (these will be addressed in see sub-chapters 9.2.5 to 9.2.8). The costs arising from institutional arrangements needed for successful marketing of enterprises are often not accounted. This issue can be handled by estimating the ROR for research and complementary services, rather than research alone.

Returns to public investment are also measured by using simultaneous equation systems by modeling growth and poverty, rather than using single equation methods which are open to standard criticism of omitted variable bias and the endogeneity of independent variables. The methods used to estimate the marginal impact are data-intensive and involve significant econometric problems. If adequate steps are not taken, they may result in biased and seriously distorted returns to agricultural research (Alston, 2002).

There has been little methodological and practical work in the area of assessing the ROR for social science research, and organizational and institutional innovations including capacity strengthening are still being developed. This 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). Another problem regarding

ROR estimates for social science research is that of assessing the combined rate of returns to social science and applied science research, as these two types of research are often undertaken jointly they are so inter-linked and difficult to isolate. Social science research can be complementary to applied science research. For example in the case of the agricultural contribution to hypoxia in the Gulf of Mexico (Box 10.3). Ribaudo et al, (2001) showed that up to a particular level of nitrogen loss from U.S. farms into the Gulf of Mexico, it would be more cost-effective to manage pollution with a fertilizer standard. Beyond that point, restoration of wetlands to absorb nutrient runoff would become more cost effective.

Since all social benefits and costs associated with R&D investments cannot be captured in the ROR estimate, a multi-criteria approach is often used to assess the performance and impact. A number of techniques can be used in the process. Despite these methodological issues involved, the available empirical evidence is sufficiently robust to make meaningful comparisons and judgments about the ROR on past agricultural R&D investments.

9.2.4. Empirical evidence

There are many studies on the ROR of investment in agricultural development. This critique draws heavily upon four major reviews (Alston et al., 2000a; Evenson, 2001 and 2003; Thirtle et al., 2001), which cover eighty% of published materials. From these reviews, we draw the following conclusions.

Rate of returns to national R&D investment. Thirtle et al. (2001) made an attempt to estimate the economic impact of agricultural R&D investment at the national level for selected countries in Africa, Asia, and Latin America. The analysis, which included 48 developing countries, revealed that the 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 9.8). The estimated ROR for the sample countries in Africa ranged between -12 and 58%, with Ethiopia, Morocco, and Uganda showing the highest ROR. In 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 as shown in Table 9.7. 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 authors concluded that the poor results for the Latin American countries are at least partly due to the limitation of data availability.

Insert Table 9.8. Comparison of ROR for national agricultural R&D expenditure across sub-regions

Rates of return to crop genetic improvement (CGI). Over the years, a significant amount of R&D resources have been devoted to genetic improvement. The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed at the International Food Policy Research Institute (IFPRI) is a partial equilibrium model covering 17 commodities and 35 country/regions. Evenson and Rosegrant (2003) used this model to assess the economic consequences of crop genetic improvement (CGI) and estimated the economic impact. The calculations were based on global market equilibrium. Table 9.9 reports the computed benefit/cost ratio (using 6% as the external interest rate) and IRRs for both national agricultural research systems (NARS) and international agricultural research centers (IARC) CGI programs by region.

The IRRs for the NARS ranged between 9 and 31%, and 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 Sub-Saharan Africa (9%). The IRRs for the IARC programs are very high and ranged between 39 and 165%. The lowest IRR was observed for Latin America. The authors concluded that these high RORs reflect the leveraging associated with the high production of IARC crosses and high volume of IARC germplasm.

Insert Table 9.9. Costs-benefits and internal rate of return for NARS and IARC CGI programs by region

Economic impacts of research and extension investments. Evenson (2001) analyzed a number of economic impact studies evaluating the contribution of agricultural research and extension programs, using the estimated ROR on investment to index economic impacts. His results are presented in Table 9.10, showing the distribution of IRRs for a number of study categories. The data are also summarized across regions, methods and commodity programs. The estimated median IRR for agricultural research for Latin America, Asia and Africa are 47%, 67%, and 37%, respectively. It was also noted that the benefit exceeded cost in Sub-Saharan Africa almost 15 years later than was the case for Latin America and Asia, causing the low IRR.
Evenson draws our attention to a number of observations:

- The mean and median IRRs reported are high and the range of estimates is very broad. Every category (except for private sector R&D spillovers) includes studies reporting both low and high IRRs;
- Research studies have higher proportions exceeding 40% than extension studies;
- Studies of commodity research programs have a higher proportion exceeding 40% (62%) than studies of aggregate research programs (57%); and
- Studies of applied agricultural research using project evaluation methods report fewer very high IRRs than the studies using statistical methods.

Evenson concludes that the available evidence suggests that the economic RORs to agricultural R&D is high. The broad scope of the evidence for high pay off suggests considerable international spillovers. Economic RORs to agricultural research are likely to be above most public and private rates (Alston et al., 2000a; Evenson, 2001; Fuglie et al., 1996).

Studies of industrial R&D indicate that the private IRRs captured by firms are generally similar to IRRs for other investments made by the firm (Mairesse and Mohnen, 1995). These studies also show considerable spillovers and indicate that the economic ROR is considerably higher than the private ones. Evenson argues that given the public sector IRRs are actually social (??) IRRs and reflect spillovers, the studies reviewed suggest that the economic IRRs for industrial R&D are also high and may well be the same order of magnitude as public sector economic IRRs.

Insert Table 9.10. Summary of IRR estimates

Many researchers (Mansfield et al, 1977; Scotchmer, 1999; Shavall and van Ypserle, 2001; Wright, 1983; Evenson and Westphal, 1995) found that 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. In agriculture in particular, firms often have difficulty in capturing much of the economic benefits of their investments (Huffman and Evenson, 1993). In the Unites States, for example, seed companies retained 30-50% of the economic benefits from enhanced hybrid seed yields and 10% of benefits from non-hybrid seed during 1975-1990 (Fuglie et al., 1996). From an strictly economical point of view, 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), however, when the objective is to reduce hunger and poverty, this practice might be used for peasants in developing countries as an strategy for independency and self-sufficiency (Shiva et al., 2000). The same authors also observed that the gap between social and private returns may be more acute in tropical agriculture, where market failures are particularly severe and poor countries that provide little intellectual property rights (IPRs) protection (Pray and Umali-Deininger 1998) lowering private returns to R&D. Even with the well functioning patent system social ROR to R&D on average are approximately twice the returns to private investors (Nadiri, 1993).

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. Evenson (2001) argues that two factors suggest that this bias may not be so serious, indicating that the available IRRs can be used for evaluation purposes with reasonable degree of confidence. The first is that one can compare the studies covering aggregate program with studies of specific commodity programs. The aggregate program includes both successful and unsuccessful programs. The second is that the evidence is based on a substantial part the world's agricultural research and extension programs.

Alston et al. (2000a) on the other hand, used the available published IRRs to address a number of specific questions. These include:(i) do the returns to more recent investments match those of investments in earlier times?; (ii) do investments in international R&D yield greater pay offs than investments in research conducted by national agencies?; (iii) is there any evidence to support research into crops yielding higher rewards than livestock research?; and (iv) what are the consequences of varying estimation techniques for the measured ROR? Do these differences in methods have implications for the interpretation of the evidence? Do some methods lead to a systematic difference between the actual and measured ROR? They assembled all reported studies for the period 1953 to 1997:A total of 292 studies reporting 1,886 rates of returns. The summary statistics on the distribution of rates of return to research, extension and both research and extension are presented in Table 9.11. Excluding the two extreme outliers the median of the ROR estimate was 48% per year for research, 63% for extension studies, 37% for those studies that estimated the returns to research and extension jointly, and 44% for all studies combined. Another analysis was performed discarding those observations with missing values, giving a total of 1,128 observations. The overall average ROR in the regression was 65% per year, with a standard deviation of 86%. The estimated annual ROR averaged 80% for research only, 80% for extension only, and 47% for research and extension combined.

Insert Table 9.11. Ranges of rates of return

Table 9.12 summarizes the distribution of ROR estimates according to the commodity orientation. Over half of these rates of returns are for crops research, 436 are for studies of research affecting multiple commodities, and 233 dealt with livestock. In these three cases the distribution of ROR is similar to that for the entire sample. A substantial difference in the distribution of ROR is observed for resources research which has a mean of 38% per year, and a median of 17% per year. These estimates mostly include forestry research, for which the research lags might be expected to be relatively long, contributing to the relatively low average rates of return. The same explanation holds for the tree crops. 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.

Insert Table 9.12 Rates of return by commodity orientation

The rate of returns by geographical region of the research is presented in Table 9.13. It is worth noting that, although the mean ROR estimates for developed countries is higher than that for developing countries (98% for developed and 60% for developing), the median are virtually identical (46 versus 43%). 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).

Insert Table 9.13. Rates of return by geographical region or research performer

Notes: Standard deviations are given in parentheses, Sample excludes two extreme outliers and includes only returns to research only and combined research and extension, so that the maximum sample size is 1,772. In some instances further observations were lost owing to incomplete information on the specific characteristics of interest.
[a] Unites States and Canada; [b] Australia and New Zealand; [c] Japan and Israel.

Some of the key conclusions of the meta analysis done by Alston et al. (2000a) are:

- Only in a subset of studies for which the benefit streams includes the 1970s, the nominal rates or return were on average 25% higher than their counterparts;
- The rate of return in ex-post analysis was higher than that in ex-ante analysis;
- Compared with measures of ROR to research, only the results suggest that measures of rates of return to extension only, or both research and extension were lower;
- Self evaluations provide significantly lower rates of return estimates;
- There is no measurable difference in estimated ROR between privately and publicly performed research;
- Compared with all agriculture, the RORs were 25% per year higher for research on field crops and 95% per year lower for research on natural resources;
- 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 a developed 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;
- The more aggregative studies generally mean lower RORs, about 40-70%;
- The ROR measure is estimated to be 16% per year lower when the results were reported in a referred journal than when they appeared as ‘grey’ literature;
- There were no differences in the estimated ROR between econometric and non econometric studies; but when the supply shift was estimated econometrically, the rate of return was lower;
- Longer gestation lag meant a lower rate of return, and the overall lag length matters;
- Unable to detect any effect of accounting for spillovers or market distortions on measured rates of return to research.

This analysis developed some insights about the sources of variation in measuring ROR and that will help in the interpretation of the empirical results. Both of these studies enable analysts to address some of the skepticisms casted on the estimated high rates of return to R&D investment. Worldwide, agricultural growth in developing countries has often been explained by a variety of factors, primarily investment in agricultural research, investment in infrastructure, investment in education and literacy, and policy changes. 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. Other decomposition study on agriculture growth and productivity in the U.S. demonstrated similar results. Shane et al. (1998) estimated that during 1974-1991 annual growth rate of agriculture productivity was 2.17% and entire economy productivity growth was 0.21% in the U.S. total factor productivity (TFP) growth rate was 2.31% 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 (25% together).

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 operating the whole system up to 2001 (Raitzer, 2003). The analysis found that the value of documented benefits generated by the CGIAR surpasses the total investment in the system. The analysts did not calculate a single benefit-cost ratio for all potential audiences, some of whom demand unassailable evidence while others willingly sacrifice a measure of precision for comprehensiveness. 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 (those studies transparently demonstrated a causal relationship and empirically attributed the benefits of research by specific CGIAR Centers) yields a benefit cost ratio of 1.9. In other words, the CGIAR has generated an indisputable (and respectable) returns of nearly 2 dollars in benefit for every dollar invested. This most restrictive analysis proved that the CGIAR is cost effective in sum but excluded many credible impacts. However, the most inclusive estimate (including those studies that demonstrated a causal relationship, without explicitly attributing the benefit to the specific centers, as well as those studies in which causality was plausible but in completely demonstrated) puts the benefits –cost ratio nearly nine times higher, at 17.3 calculated in 1990 dollars, this most generous estimate converts the 7 billion investments up to 2001 into US$123 billion in benefits by 2011.

But this remarkable value is only part of the story of the CGIAR's impacts. The approach this analysis took actually excluded the benefits from the vast majority of the CGIAR's 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 International Agricultural Research Centers of the CGIAR since the System's establishment. Under very conservative assumptions, benefits generated (through 2001) from only:1) new, higher-yielding rice varieties in Latin America, Asia, and West Africa; 2) higher-yielding wheat in West Asia/North Africa South Asia and Latin America; and 3) cassava mealybug biocontrol throughout the African continent total almost twice the aggregate cumulative CGIAR costs. If slightly more generous assumptions are 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.

These three innovations comprise only a small subset of the CGIAR's research activities. If impact assessment were applied to a larger proportion of the System's portfolio, much higher aggregate benefit values may result. Furthermore, the aggregated studies do not take into account multiplier effects that result from stimulated growth in the non-farm economy, or non-market benefits, As a result, even the most generous of the values reported may be considered as conservative. To go further, ex-post impact assessment must be applied more broadly within the CGIAR System. The bottom line remains that investment in the CGIAR has paid off handsomely, even when analyzed from the most conservative perspective.

The two efforts made to compile the available case studies on ROR for African agricultural R&D investment confirm these aggregate findings (Table 9.14). In the first study Oehmke et al. (1997) reviewed economic impact studies across Sub-Saharan Africa. 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 agro-ecological 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%. In the second study, Anandajayasekeram et al. (2006) reviewed the impact studies conducted in Eastern and Southern Africa (ESA) during 1978-2005. The RORs for those studies using the non econometric methods ranged between 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 Africa are similar to those found elsewhere, showing a high pay off for a wide range of programs.

Insert Table 9.14. Summary of results of Economic Assessment of African R&D Investments

9.2.5. Environmental impacts of agricultural R&D investments

In this sub-chapter an attempt is made to present the evidence available on the environmental consequences of the R&D investment on crops, fishery, and livestock. However, the issue has been widely discussed in chapter 3, so we would just refer some further studies to complement the evidence and issues raised. The success of modern agriculture in recent decades has often masked significant externalities, affecting both natural resources and human health, and thus, the underpinning of agriculture itself. Environmental and health problems associated with modern agriculture have been increasingly well-documented, but it is only recently that the scale of the costs and benefits has come to be appreciated.

Agriculture by definition changes the environment. With each new technology and ability to farm land more intensely or extensively, impacts on the environment are produced, and some are positive while many are negative. For example, the use of fertilizers or pesticides may lead to surface and ground water contamination by toxic chemicals and algae, resulting in significant environmental costs (Clay, 2004). On the other hand, adoption of minimum tillage technology by farmers has probably had environmental benefits in the form of reduced soil erosion. Environmental impacts depend on many external forces. Different agro-ecological zones, market conditions, and financial and social incentives as well as technologies play significant roles in determining the breadth and depth of their impacts.

In the past the objectives of AKST investments have been to largely to increase yields and to improve food security. , Thus the environmental costs and benefits of agricultural technologies were not usually considered. Until to date they are seldom measured and even less often converted into monetary equivalents. Although many economic valuation techniques have been developed and refined over the last twenty years, to obtain the monetary value of environmental impacts faces practical difficulties. There are basically two reasons for this. First, the issue of time and scale complicates the data collection and valuation. Second, most studies are not linked to a specific agricultural technology, rather, more general issues such as biodiversity loss, soil erosion, and land tenure, and so on, which are more difficult to measure. Thus, there are important methodological issues as discussed above, of which the most significant is the problem of different scales and time frames. Many of the environmental impacts are accumulative by nature, as in the case of hypoxia in the Gulf of Mexico (see box 9.3), gradual salinization of irrigated fields, and the reduction of in-situ genetic diversity of major crops. Geographic scale is also critical in some instances, 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. The ROR estimates presented earlier ideally require to complement society-centric models, as our concern is who pays, who benefits from investment in agricultural R&D. The major constraint to the limited inclusion of environmental benefits and costs in ROR analysis , are lack of data due to measurement problems.

Insert BOX 10.3. The hypoxic zone in the northern Gulf of Mexico is the largest observed in the estuarine and coastal regions of the western hemisphere

With respect to time, the introduction of exotic species and varieties may have significant impact on the productivity and income of the farmer, yet over time and scale, it may result in the loss of local agro-biodiversity as farmers replace each year more and more indigenous species with exotic species. Thus the agro-biodiversity loss is only experienced over a significant timeframe. In our view, the most important environmental considerations of agricultural technologies are those that have a significant and accumulative - over time and space – impact downstream effects. In other words, in most cases, the environmental concern is whether communities away from the source of externalities suffer or benefit at significant levels from the environmental impacts of 'upstream' agricultural technologies. In general, the environmental impacts can be on-site market effects, off-site market effects, on-site non-market effects, or off-site non-market effects.

The accumulative environmental impacts are also very important. Given the current trajectories of area expansion and intensification in agriculture, fisheries and forestry, it is likely that humans will expand onto and degrade most habitable areas of the planet (Clay, 2004). Thus, the very base of resource stock is at question:water and soil quality, carbon sequestration, biodiversity, and thus, our ability to feed and shelter growing populations. The key environmental issues of relevance are:biodiversity loss on- and off-farm; erosion and soil quality; run-off of agro-chemicals; impact on non-target species of pesticides; water table loss; and use of non-renewable energy. These issues need to be considered for crops, livestock, fisheries and forestry.

Our concern is with on-farm biodiversity, referring to both crop and livestock species diversity (linked to livelihoods diversity) and plant and animal genetic diversity. Modern agriculture has greatly narrowed the species and genetic diversity of crops, and over ninety% of our food crops come from thirty species. Several authors have stated that agricultural biodiversity is essential for food security (Pimbert and Pretty, 1997; Thrupp 2000; Frison et al., 2004). With respect to worldwide soil erosion, estimates range from around 65 to 80% of agricultural land suffers moderate to severe erosion and another 10% slightly to moderate. Southeast Asia has been found to be the most seriously affected region in the world. It is estimated that nearly 60% of present soil erosion has been induced by human activity. Global warming might significantly increase the potential for soil erosion, and the regions with the same increasing trend of precipitation and population might face much more serious problems related to soil erosion in the future (Yang et al, 2004). 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). Improper irrigation and drainage can cause salinization, and an estimated 20% of the world's irrigated lands suffers yield reduction due to some salinization (Ghassemi et al, 1995 as cited in Clay, 2004). Many farming technologies such as open plowing, slash and burn, intense mono-cropping and hillside cropping provoke soil erosion. On the other hand, through improved technologies such as non-till cultivation, erosion can be reduced.

Some of the most damaging impacts of input-intense agriculture stems from the use of agrochemicals (Clay, 2004). The specific crop, size of production, type of chemical and how the farmer uses each chemical, including improper use, all determine the environmental impact, both positive and negative. Major impacts of using agro-chemicals include:the loss of non-target pests, human poisoning, run-off and leaching, and development of resistance. There is no global mechanism to track pesticide related illness, and thus data and trends are difficult to determine. However, the Pesticide Action Network North America estimates acute pesticide poisoning to affect as many as thirty-nine million people worldwide (Reeves et al, 2006). Irrigated rice in Asia is a good example of health impacts of pesticide use in connection with the introduction of modern varieties. Earlier Green revolution rice varieties were highly susceptible to pest attacks, which stimulated the rapid introduction of chemical pesticides. Furthermore governments adopted a policy of subsidizing chemicals in order to assure high yields and productivity growth (Repetto, 1985, Waibel, 1990). Several studies showed high costs to human health, e.g. Rola and Pingali (1993) found health costs of insecticide use to be at par with the costs of control, while Loevinsohn (1987) conducted an epidemiological study in which he estimated that the accepted figure of 10,000 Asian deaths from pesticide poisoning was a substantial underestimate. In another example from Paraguay (Stemino et al. 2006) health and other negative effects were reported from the expansion of soybean cultivation in Paraguay (see also subchapter 9.2.6 on health issues).

Waterways are also impacted by erosion and agrochemical run off. The level of nutrients such as nitrates and phosphorous in freshwater ecosystems is a problem worldwide (Shiklomanov, 1997). In most cases, the major cause of these contaminants is the increased use of manure and manufactured fertilizer in global agriculture. It varies from region to region, and the analysis of the cost is hampered by lack of comparable data across regions. An analysis of more than 3,000 watersheds across the Caribbean region estimated that about one –third of coastal waters are likely to experience increased sediment and pollutant delivery related to land-use activities (Burke and Maidens, 2004). In the United States agriculture is the single most source of pollution degrading the quality of surface waters like rivers and lakes, with croplands alone accounting for nearly 40% of the nitrogen pollution and 30% of the phosphorous (Faeth, 2000). Furthermore, in the United States, over 70% of rivers and 52% of lakes studied were found polluted by agrochemicals (US EPA, 1994). Likewise, in Europe, a recent study showed the main source of phosphorus pollution in the Mediterranean basin is agro-chemical run-off (Cherlet, 2006). Similar evidence can be found in many lakes and sea basins around the world such as Lake Victoria in

East Africa, Panantal in Brazil, and the Gulf of Mexico. The exact monetary costs associated with these damages stemming specifically from agricultural inputs upstream are very difficult to estimate.

The full assessment of environmental quality effects requires complex analysis of physical, biological, social and economic processes. There are very few studies that incorporate social and environmental externality costs and benefits in IRR estimations; largely due to data and valuation problems, although in the future incorporation of these non-market costs and benefits may become more common. In the absence of data required for a thorough analysis, it is possible to identify qualitatively the nature of the social costs and benefits together with the likely winners and losers. Table 9.15 summarizes the general trends in environmental impacts of agricultural technologies.

Insert Table 9.15 General trends in environmental impacts of agricultural technologies

An Environmental Impact Assessment (EIA) is an activity designed to identify and predict the impact of an action on the bio-physical environment, on individuals' health and wellbeing, and to interpret and communicate information about the impacts (Munn, 1979). EIA are important because the non-market effects of a technology can be significant. EIA is becoming increasingly important due to concerns for ecologically sustainable development, which it has been shown to be positively related to the reduction of poverty (UNEP, 2004). 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. In the past, the multidisciplinary nature of the environmental issues has caused problems with the quality and general availability of data. For example, R&D effort might lead to the development of fertilizers that have long term negative effect on soil. To incorporate such externalities, the physical effects on soil would need to be monitored closely by the scientists before their economic impact could be estimated. Another problem is obtaining statistically reliable field specific data. Reconciling different levels of aggregation to obtain reliable estimates is another issue confronting the analysts. 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, etc. The problem is how to generate information that reflects the physical, biological and economic diversity of the region/nation under study and how to combine this information to yield reliable information about the region/nation. In terms of valuation, the most difficult ones are those dealing with biodiversity and their benefits and costs requiring the use of non-market valuation techniques. However, there are some tools, like the Ecological Footprint (Wackernagel and Rees, 1997) which can be useful to quantify 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. Many authors have already used this tool, for instance Kautsky et al. (1997) used this approach to measure the ecological footprint to asses the resource use and development limitations in shrimp and tilapia aquaculture. Also parameters such as the energy flow or the food miles can be used to measure non-monetary impacts. Other brands of the economic science, such as ecological economics can bring promising tools in the future to measure these externalities (Proops, 1989; Jacobs, 1996). For example, Pretty et al. (2000) estimated that total external environmental and health costs of modern agriculture in the United Kingdom were £2343 million in 1996, equivalent to 89% of average net farm income and £208 per hectare of arable and permanent pasture. Significant costs arose from contamination of drinking water with pesticides (£120 million per year), nitrate (£16 million), cryptosporidium (£23 million), phosphate and soil (£55 million), damage to wildlife, habitats, hedgerows and drystone walls (£125 million), emissions of gases (£1113 million), soil erosion and organic carbon losses (£106 million), food poisoning (£169 million), and from bovine spongiform encephalopathy (£607 million). The study only estimated those externalities that give rise to financial costs, and so is likely to underestimate the total negative impacts of modern agriculture. To Pretty (2000) the goods and services produced by the natural and social capital in rural areas are extremely valuable and we all, to a certain extent, derive benefit from our farming and rural systems. But we could get more. Half a century ago, at least half of the amounts spent on food found its way back to the farmer and rural community. In order to create a more sustainable food system, more value needs to be added to or be captured by rural communities and farmers. Pretty argues that there are five key options for capital accumulation in rural areas:adopt sustainable agriculture; selling of produces, directly to consumers; enhance links with community co-operatives; creating farmers' groups; eco-labeling. The emergence of community food security and the idea of the foodshed as integrating concepts can help communities to take back more of the middle. The foodshed, by bringing consumers and producers literally and figuratively closer, helps to regenerate and reinvigorate natural and social capital. To him, few say that autarkic systems with no external linkages are best. Rather it is a question of making the best of local capacities, resources and linkages before turning to externally-sourced products. System-wide changes are possible, provided that local and national policies are enabling. (To be completed, ecological economy. Energy flows and other non-monetary tools:contributing author)

An overview of the link between some AKST and their related potential negative externalities has been addressed in a study commissioned by the SPIA (Maredia and Pingali, 2001). The results are summarized in the Table 9.15. The key results are ………..

Insert Table 9.16. Estimates of negative externalities of productivity-enhancing technology[*] in developing countries:Evidence from the literature.

Irrigated induced externalities have been calculated using the land savings approach (Table 9.17.)

Insert Table 9.17. Estimates of negative environmental consequences and land-use implications of irrigation-induced soil salinity problems in developing countries, late 1990s

Examples of environmental impacts on crops, aquaculture and livestock. The effect of crop science and technologies on the environment is a broad issue, which includes different aspects such as the seeds (including GM crops and potential loss of biodiversity) and the technological package for high yielding varieties (pesticides, fertilizers, etc). In the first group the literature is contradictory, probably because GMOs are not a single, homogenous technology. Each application and product brings different benefits for different stakeholders, each poses different environmental and health risks (Pretty, 2001). With respect to the technological package, literature seems to agree that the indiscriminate use of pesticides have had negative impacts on the environment, both in the process of manufacturing, which utilizes big amounts of fuels, and during the utilization of inputs on field.

GM crops may potentially have negative and positive effects on the environment. Potential environmental risks from the use of GM crops can be classified under several headings. Transgenic crops do not present new categories of environmental risk compared to conventional methods of crop improvement (Ervin and Welsh, 2005). Nonetheless, with the long-term trend toward increased capacity to introduce complex novel traits into the plants, the associated potential hazards, and risks, while not different in kind, may nonetheless be novel (NRC, 2002). The U.S. National Research Council (NRC, 2002) defines four kinds of potential hazards from GM crops:1) evolution of resistance to the genetically engineered toxin by the targeted pests, leading to fewer rather than greater options for pest control and increasing of pesticides use; 2) gene movement from the engineered crops, leading, for example, to increased weediness of wild relatives; 3) whole plant effects, for example the development of feral populations of herbicide resistant crops; and 4) impacts on non-target organisms, for example through toxicity to non-target and beneficial organisms, or impact on animal populations through reduced food supply. Potential environmental and economic benefits from the use of GM crops include more efficient or reduced pesticide use, or substitution of pesticides that are less harmful to the environment for more harmful chemicals; and reduced tillage, erosion, carbon loss, or water savings (OECD, 2004; Ervin and Welsh, 2005). To date, the relatively short amount of time for which GM crops have been planted has limited the available evidence on the categories of risk. More data and new models may be necessary to analyze the long-term unexpected environmental effects of transgenes, especially the level and consequences of gene flow or the impact on non-target organisms. Some examples of resistance evolution have been documented, but the overall economic effects are not yet clear (Ervin and Welsh, 2005).

Studies on the environmental impacts of GM crops have focused primarily on changes in pesticide use. Fernandez-Cornejo and Caswell (2006) reviewed nearly 30 studies of the effects of GM crops in the United States. Of the 13 studies that reported changes in pesticide use, 11 reported decreased use associated with the use of GM crops. One showed no change, and one study showed an increase in herbicide use associated with planting of HT soybeans. Brookes and Barfoot (2005), in an industry-financed study, assessed the global environmental impact of GM crops (GM HT soybeans, maize, cotton, canola, GM IR maize and cotton) with respect to pesticide usage and green house gas emissions for the periods 1996-2004. Since 1996, the use of pesticides was reduced by 172 million kg (6% reduction). In absolute terms, the largest environmental gain was associated with the adoption of GM HT soybeans. Brookes and Barfoot, however, do not provide the sources of the data used to estimate changes in pesticide use. On the other hand, Benbrook (2004) reported that GM corn, soybeans (which accounted around half of total GM crops in the United States) and cotton led to a 56 million kg increase in pesticide in the period 1996-2004 in the United States. According to Benbrook, Bt crops reduced insecticide use by about 7 million kg over this period while HT crops increased herbicide use by 63 million kg, mainly due to the emergence of involuntary HT weeds. This result appears inconsistent, however, with estimated aggregate application rates (use by all crops, whether GM or not) of pesticides in United States agriculture. According to Fernandez-Cornejo and Caswell (2006) from 1995 through 2002, application rates for maize herbicides, maize insecticides, and cotton insecticides fell, while application rates for soybean herbicides rose slightly.[11] Use of GM crops in other OECD countries has to date been insufficient to determine effects on pesticide use (OECD 2004). Thus the available evidence is inconclusive so far in terms of the effects of planting GM crops on global pesticide use. In a review of the applied economics literature about the impact of genetically improved crop varieties in developing counties Smale et al (2006) found that the initial enthusiasm for the technology has been superseded by a more cautious weighing of its economic advantages and disadvantages. Furthermore, the authors identified a number of methodological limitations that restricts drawing solid conclusions about the impact.

United States data suggest some increases in glyphosate use, particularly associated with planting HT soybeans, and reduction in other pesticides. The issue here is not simply the quantity of pesticide but also the nature and the properties of the pesticide used. Furthermore, for the most part other environmental impacts such as increased resistance or gene flow have not been assessed on a large scale. In addition, the environmental effects of GM crops need to be considered in a dynamic, ecological way, not in a static, snapshot kind of way since they are released into a highly adaptive, interactive environment of soil, plant animal interactions subject to varying evolutionary pressures.

Over the course of the past century, as a result of the so-called Green Revolution, that promotes monocultures, together with the commercialization of agriculture, technical change, and changes in habitat have led individual farmers and regions to specialize in the production of fewer crops and varieties (Gepts 2006). Upreti and Upreti (2002) argue that monocultures have had severe effects on biodiversity in the developing countries. They claim that expansion of hybrid and cross-bred varieties, increasingly introduced by multinational companies through local traders, is threatening biodiversity conservation and enhancing the erosion of genetic species and agroecosystem diversities, replacing local varieties of vegetable and cereal crops as well as ignoring indigenous knowledge. Monocultures have also important impacts on the rural landscape. The spread of scientifically bred varieties, however, has differed considerably by crop, region, and time period (Evenson and Gollin, 2003). Careful studies have been done for spring bread wheat, a crop for which the Green Revolution varieties have largely replaced traditional varieties. They suggest that since the introduction of these varieties in the mid-1960s, a single core germplasm has been the basis of much of the spring bread wheat that has diffused through developing countries. At the same time, there has been no evidence of genetic narrowing within this germplasm, whether assessed by pedigree-based or molecular measures, and phenotypic diversity is substantial. Potential diversity indicators such as tolerance to heat and drought, resistance to disease, nitrogen use efficiency, and yield stability have all increased (Dreisigacker et al. 2004; Smale et al. 2002). In short, individual diversity indicators within some scientifically bred crops have moved in favourable directions since the Green Revolution. However, considering different varieties of one crop, impacts of commercialized agriculture and monocultures on biodiversity have probably been substantial, particularly at the ecosystem level.

The studies conducted so far show both a negative and positive impact of aquaculture on the environment, mostly depending on the intensification of the production systems. Brummett (1999) tested an incremental farmer participatory approach to the development of sustainable aquaculture in integrated farming systems in Malawi. Comparing the small-scale integrated farming systems with the purely commercial fish farms, he found that the integrated farming systems are more efficient at converting feeds into fish and produce fewer negative environmental impacts. The integrated farming systems have the advantage of not using one human foodstuff to produce another. Hence, the widespread adoption of integrated aquaculture might actually improve local environments by reducing soil erosion and increasing tree cover (Lightfoot and Noble, 1993; Lightfoot and Pullin, 1995; Brummett, 1999). On the other hand, other authors have found a negative environmental effect of aquaculture industry (Naylor et al., 2001; Gundwardana, 2005). Naylor et al. (2001) state that some types of aquaculture are on a destructive path that poses a threat not only to wild fish stocks but also on the marine environment, which is degraded. The authors further explain that impacts of the industrial aquaculture include:(i) destruction of

hundreds of thousands of hectares of mangrove forests and coastal wetlands for construction of aquaculture facilities; (ii) use of wild-caught rather than hatchery-reared finfish or shellfish fry to stock captive operations, which often leads to a high rate of discarded by catch of other species; (iii) heavy fishing pressure on small ocean fish for use as fish meal, which can deplete food for wild fish; and (iv) transport of fish diseases into new waters and escapes of non-native fish that may hybridize or compete with native wild fish. Evidence also shows that improvements in management can help to reduce the environmental damage (Lebel et al., 2002), but only to a minor extent. However, it is worth noting that the economic impacts are site specific. In the case of aquaculture, some work has been done on by including both market and nonmarket costs and benefits in order to evaluate the total effect of the systems to show the real economic impact of the production systems. In a simple cost-benefit analysis, industrial shrimp farming is found to be really profitable, however, if we include other parameters (ecological or social) the situation is reversed. A cost-benefit analysis performed in India concluded that shrimp culture caused more economic harm than good. The damage outweighing the benefits by 4 to 1 or 1.5 to 1, depending on the areas considered (Primavera, 1997). These cost included loss of mangroves, salinization and increasing unemployment. Blamford et al. (2002) found that total economic value of an intact mangrove in Thailand exceeds that of shrimp farming by 70%. Barraclough and Finger-Stich (1996) pointed out that these social and environmental problems are only the latest incidents in the broader processes associated with the expansion of other monocultures (banana, cotton, coffee, sugar) that have generated social exclusion and environmental degradation.
Finally, intensive aquaculture has also had important effects on the landscape. For example, in Thailand 50 to 65% of the mangroves have disappeared due to the culture of shrimp (Barbier and Cox, 2002). Mangroves have been substituted by shrimp ponds, decreasing also the quality of the landscape.

Recently, livestock production has increased rapidly, particularly in developing countries where most of the increased production comes from industrial farms clustered around major urban centers (FAO, 2005c). Such large concentration of animals and animal wastes close to dense human population often causes considerable pollution problems with possible negative effects on human health. A study by FAO (2005c) argues that concentrated, large-scale livestock production often creates concentrated, large-scale environmental problems. Large industrial farms produce far more waste than can be recycled as fertilizer and absorbed on nearby land. When intensive livestock operations are crowded together, pollution can threaten the quality of the soil, water, air, biodiversity, and ultimately public health (FAO, 2005c). Comparing less intensive, small scale livestock production with industrial large scale production, the study states that in less intensive, mixed farming systems, animal wastes are recycled as fertilizer by farmers who have direct knowledge and control of their value and environmental impact. However in industrial production, there is a longer cycle, in which large quantities of wastes accumulate creating regions with vast quantities of excess manure. Furthermore, the study shows that livestock production is a major contributor of emissions of polluting gases, including nitrous oxide, a greenhouse gas whose warming potential is 296 times that of carbon dioxide. Steinfeld et al. (2006) showed that livestock contributes 18% of the total global warming effect, larger even than the transportation worldwide. The share of livestock production in human-induced emissions of gases is found to be 37% of total methane, 65% of nitrous oxide, 9% of total carbon dioxide emissions and 68% of ammonia emissions (Steinfeld et al., 2006). The authors also warn of the effect of large-scale industrial livestock on the pollution of water, in a world that presumably will have lack of access to freshwater in the near future.

Other serious threat of large-scale industrial agriculture and livestock on the environment is that of deforestation to increase the cropland dedicated to the production of feed-crops and fodder to feed animals (Steinfeld et al., 2006) or, recently, to produce biofuels. Remarkable are the examples of the Amazonia in Brazil, the Yungas and the Chaco in Argentina and Paraguay (Fearnside, 2001; Pengue, 2005; Greenpeace, 2006). These highest rates of deforestation have important implications in the global warming worldwide. Other added environmental impact is that produced by the transport of seeds to feed the animal from Southern countries to Northern, which includes the consumption of fossil energy and gas emissions. However, livestock cannot be blamed for producing the impacts commented. The problem with livestock arises when it is produced far away from crop agriculture. Livestock and crop agriculture have always been a complement to each other, as shown by mix farming practices, where animals and crops are grown together and where the cycle of nutrients is naturally closed (Lantinga et al., 2004).

Traditional and local knowledge. Traditional and local knowledge of a community in agrobiodiversity management and utilisation is derived from local people's farming experiences and is passed down to posterity. It entails many insights, perceptions, and institutions relating to local environments. Upreti and Upreti (2002) found that traditional and local knowledge and farming systems associated are either ignored or sidelined by new technologies and profit-oriented interventions.

Hesse and McGregor (2006) have developed a new conceptual framework to assess the value of pastoralism that goes beyond conventional economic criteria in order to provide fresh insights to its contribution to poverty reduction, sustainable environmental management and the economic development of dryland areas of East Africa in the context of increasing climate uncertainty. Pastoralism is a typical example of indigenous knowledge linked to a diverse and dynamic livelihood system integrating livestock husbandry with other activities including agriculture and non-timber forest products. Although livestock are raised for economic reasons these are framed within strong social, environmental and cultural objectives. Pastoralism is also well-adapted to, and able to generate significant returns from dryland environments with scarce and unstable resources and it is recognised by the authors as a rational economic land use system in which maximum returns, be they economic, social or environmental, are sought from investments. *Direct values* of pastoralism include production of milk, beef and hides for subsistence and export, but these are rarely included in the national accounts, even when as inputs to the formal sector. Indirect values include income from tourism, 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 recognised by policy makers. Also, existing national statistics are inadequate and inaccurate. All this leads to an undervaluation of the contribution of pastoralism and the promotion of policies that is seeking to change or replace it thereby causing a vicious circle of impoverishment, conflict and environmental degradation in dryland areas.

One issue related to traditional and local knowledge is that of endogenous livestock development and the ethnoveterinary medicine for livestock (EVM). In the last few years a growing interest exists for ethnoveterinary and big efforts are being made to recuperate all these knowledge that has been neglected for centuries.[12] Ethnoveterinary medicine differs from the paternal approach by considering the traditional practices as legitimate and seeking to validate them (Köhler-Rollefson and Bräunig, 1998). According to Tabuti et al (2003) systematic studies on EVM can be justified for three main reasons, they can:(i) generate useful information needed to develop livestock healing practices and methods that are suited to the local environment, (ii) EVM could be a key veterinary resource and could add useful new drugs to the pharmacopoeia, and (iii) EVM can contribute to biodiversity conservation.Thus it is important to recognize that the environmental consequences of AKST investments are critical in assessing the returns to investments. Ignoring them in any rate of returns studies may lead to erroneous conclusions.

9.2.6. Health impacts of agricultural R&D investments

The interactions between agriculture and human health are well recognized. They can be illustrated in a framework as depicted in Figure 9.8. Agricultural technologies through their effects on productivity, income, food quality and food security on the one hand can improve the health status of the people engaged in the production of food. For example, breeding crop varieties with higher levels of micronutrients can avoid malnutrition and related diseases. If people are food secure and they are more healthy which positively affects their productivity. On the other hand, agricultural technologies, like for example chemical pesticides can have negative effects on the health status of farmers, farm laborers, farm household members and also on food consumers.

Insert Figure 9.8 Conceptual framework of the linkages between agriculture and health

An example of recent AKST investment is the research associated with biofortification. Biofortification aims to reduce malnutrition by breeding essential micronutrients into staple crops. Such breeding efforts bridge the fields of human nutrition, crop science and public health to develop in order to develop cost-effective nutrition interventions complementary to existing nutritional interventions. It is believed that biofortification can help to overcome micronutrient deficiencies. Micronutrient malnutrition is often referred to as ‘hidden hunger’ and for certain micronutrients such as iron, zinc and iodine the deficiencies are even more widespread than calorie under nutrition (WHO, 2002; Hotz and Brown, 2004; UN-SCN, 2004; FAO, 2004). The adverse health outcomes of micronutrient deficiencies includes child and maternal mortality, impaired physical and mental activity, diarrhea, pneumonia, stunting or blindness, among others (Stein et al., 2005a)

A number of research and development programs with the objective to increase micronutrient densities in staple food crops through breeding have been launched in recent years. The Harvestplus Challenge Program of CGIAR, concentrates on increasing iron, zinc and beta-carotene (provitamin A) content in six staple crops species namely rice, wheat, maize, cassava, sweet potatoes and beans and supports exploratory research in ten additional crops (Qaim et al., 2006). Most biofortified crops are still at the stage of research and development, except beta-carotene rich orange fleshed sweet potatoes and golden rice which have been promoted in different countries (Low et al, 1997; Ye et al, 2000; Pain et al, 2005, Goto et al, 1999; Lucca et al, 2001; Murray–Kolb et al, 2002; Asconcelos et al, 2003; Drakakai et al, 2005, Ducreux et al, 2005). The impact of biofortified crops on human health depends on its efficacy (micro nutrient content, micro nutrient retention and bio availability) and coverage (farm adoption and consumer preference).

Zimmermann and Qaim (2004) in their analysis of potential health benefits of Golden Rice in the Philippines concluded that micronutrient causes significant health costs, which could be reduced through biofortification. They quantified the health cost of vitamin A deficiency with and without Golden Rice and interpreted, the health cost saved as benefit of the technology. Dawe et al. (2002) investigated the potential nutritional effect of Golden Rice by analyzing likely improvements in vitamin A intake in the Philippines. He found that while such variety may have good potential its adoption may be limited as there may be other negative traits of the variety. In a preliminary assessment of iron biofortification in India and Bangladesh, Bouis (2002) estimated the reduction in the number of anemia cases and attributed a monetary value to each case averted. There are different methodologies available for the quantification of health costs, including budgeting medical treatments, estimating productivity losses, and willingness to pay approach (Brent 2003). Qaim et al (2006) in an ex-ante impact assessment used the disability adjusted life years (DALYS) approach to estimate the health cost saved (Lomborg, 2004, WHO, 2002, Stein et al, 2006) using an optimistic and a pessimistic scenario and making assumptions for the economic value of DALYS. The estimated Internal Rate of Return (IRR) for the pessimistic scenario ranged between 31 to 66% and that of the optimistic scenario ranged between 70 to 168%.

Further ex-ante studies on the expected impact of biofortification research under the Harvest Plus 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. Predicted health cost reductions have been calculated based on the micronutrient amounts that the breeders reckon they can achieve using conventional breeding techniques. Following the study of Meenakshi et al. (2006) depending on crop and location, health cost reductions range from 11 to 64% in the optimistic scenario and from 3 to 38% in the pessimistic scenario. It is important to keep in mind that once the biofortified crops are disseminated, additional empirical work is required including ex-post studies building on observable data to verify the preliminary results reported by the various authors. Further research is also needed on the bio-availability and micronutrient interactions in the human body. For example, it has been argued (Qaim et al, 2006) that iron and zinc content go hand-in-hand for several crops, and their combined impact may be greater than what a single nutrient alone may achieve. The key conclusion is that biofortification could play an important role in achieving the nutrient security in particular situations only. However, this also depends 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 all over the world promoted by the adoption of some technologies. On the one hand, livestock products contribute to improve nutrition globally. But, on the other hand, is also linked to diseases such as cardio-vascular disease, diabetes and certain types of cancer (Walter et al., 2005). Furthermore, the related indirect effects of the increase of food production and availability on the changes and homogenization of consumption habits have lead to obesity, both in developed and developing countries. Obesity has been called one of the epidemics of the twenty-first century (McCarthy, 2004) and nowadays represents a heavy burden for the health system in developed countries. Its causes are complex and diverse and in some instances, obesity occurs at the same time as malnutrition. This implies that increasing production of agricultural and livestock products and thus, decreasing its market price, have to be accompanied by policy measures to avoid market failures leading to health problems, such as obesity (McCarthy, 2004).

Pesticides are another good example of AKST that has shown negative effects on human health. WHO (1990) estimates that there at least 1 million cases of pesticide poisoning annually, with women and children in developing countries disproportionably affected (UNEP 2004) Another study puts the total number of unintentional fatal poisonings from all sources that includes those from agricultural chemicals at 350 000 per year (WHO, 2006). These global figures are neither collected systematically nor on a regular basis. Hence the likelihood of underreporting is high. Estimation of the incidence of pesticide poisoning is difficult, since the surveillance systems may be inadequate and tend to underreport (PAHO, 2002; London and Bailie, 2001). Thus, reported rates of poisoning incidence tend to underestimate true levels of pesticide poisoning and therefore official reports represent lower bound estimates. For example, a study that looked at pesticide underreporting in the national health surveillance system in the Central American countries found an overall rate of 4.9% of pesticide intoxications in the exposed population (Murray et al., 2002). A study of the reporting procedure of pesticide poisoning by the public surveillance system in Nicaragua put the rate of underreporting at almost hundred% (PAHO, 2002). Evidence of the pesticides poisoning is also supported by numerous case studies. Most of these studies show that farmers in the developing world are highly exposed to human health risks when using pesticides. Studies in Malaysia and Sri Lanka found that around 7% of the exposed agricultural work force suffers from acute intoxication (Jeyaratnam et al., 1982; 1987). Similar figures were found in Indonesia (Kishi et al., 1995) where 9% of surveyed farmers reported poisoning in the year before the survey. A study in Ivory Coast showed that depending on the type of production system, between 8 and 37% of cotton farmers suffered from pesticide poisoning symptoms for which they had sought cure (Ajayi, 2000).

Economic studies mostly carried out in developed countries (Pimentel et al., 1992; Waibel et al., 1999) tried to put an economic value on pesticide externalities of the agricultural sector. They found that health costs make up about 10% of the total externality costs of pesticides. A study from pesticide use in Philippine rice production (Rola and Pingali, 1993) found that health costs were at par with the costs of insecticides used by Philippine rice farmers. Adding health costs to the costs of insecticides rendered the use of insecticides in rice to be uneconomical. Using a health production function approach, Antle et al. (1998) in a study of Ecuadorian potato producers found significant health costs mainly from the use of Carbofuran. Other studies in South America have established similar evidence (e.g. Crissman et al., 1994; 1998). Some authors (Cuyno et al., 2001; Garming and Waibel, 2006) established that farmers reveal a positive willingness to pay for reducing the negative health effects from chemical pesticides.

For a long time it was assumed that the main cause for pesticide poisoning is a lack of awareness of the dangers of pesticides and a lack of information about the proper handling of toxic substances. Consequently, considerable investments were made by the public sector and the chemical companies on safe use training. Pilot projects were carried out in Mexico, India and

Zimbabwe (Atkin and Leisinger, 2000), Guatemala, Kenya and Thailand (Hurst, 1999). Success of pesticide safe use training however was very limited. After the training was over, farmers often went back to their old practices (Atkin and Leisinger, 2000). Also it was found that personal protective equipment, hygienic practices after spraying, compliance with re-entry intervals, safe storage of equipment and pesticides are measures often not feasible in tropical climates and under the conditions of poor countries (Cole et al, 2000).

Summing up the evidence on the pesticides this type of technology is probably the clearest case where an AKST product has caused health (and other) externalities. This does not mean, however, that the net social benefits of this technology were negative. Likewise it remains yet to be seen to what degree and at what scale new pest control technologies like for example biological control or genetically modified pest and disease resistant varieties will substitute toxic chemicals in agriculture. As Ecobichon (2001) suggests, pesticides use in world agriculture continues to rise and the concerns about their implications for human health will remain.

In any case, apart from discussing whether AKST can have positive effects on health, as shown with the biofortification, or negative, as shown with the pesticides, it is necessary to consider the policies that accompany the results of AKST. It is important to reflect on whether the objective is to obtain maximum benefit from the commercialization of the results or to provide a benefit to the society, and the results would be quite different depending on the objective. For example, the global performance of GM crops all over the world could be assessed primarily by level of commercialization, which has been substantial but primarily concentrated in a few countries. Alternatively, they could be evaluated on the degree to which GM technology has been used in food as opposed to feed crops; the extent to which they have had impacts on the livelihoods of small scale farmers; the impact they have had on the environment; and the degree to which they have provided new consumer benefits. GM crops are neither good nor bad in themselves, but the global policies of the market which affect the GM crops use and commercialization, which have relatively little to do with the AKST, have a large impact on their societal impact. So far the available evidence is inconclusive. Thus targeted studies and policy changes including consumer education are needed to fully understand and assess the impact of GM on society.

9.2.7. Incorporating non-market impacts into economic analysis.

A few studies have incorporated environmental or health effects directly into economic estimates of costs and benefits, for example the studies on the environmental effects of aquaculture or the health effects of pesticide use cited above. Most economic analyses do not, however, attempt to incorporate these costs or benefits. Instead, other methods are used to assess non-market impacts of agricultural R&D. Even though a wide variety of agricultural research is likely to have environmental impacts, Alston et al.'s (2000a) study of ROR analyses confined itself primarily to examples from forestry or fisheries research when discussing natural resources research.

Increasingly, however, it is likely that valuation of non-market impacts of agricultural R&D will be incorporated into economic analysis. Past studies have kept from addressing these issues because of measurement difficulties and the fact that research impacts directly observable in commodity and factor markets were abundantly available. Research systems, however, are called upon more and more to provide positive non-market environment or health benefits as well as to mitigate past negative impacts, and so these benefits will become more important to impact analysis.

Agricultural research may provide positive benefits in environmental, health, or other non-commodity areas through a variety of means. Some may come through direct technology development, such as research to improve nutrient management on farm, or to absorb nutrient runoff before it reaches water that has alternative uses, or research to improve the nutritional content of crop varieties. Other research may develop tools that can enhance the environment such as better methods of predicting soil loss or nutrient runoff, which can be used to achieve better environmental management. Social science research may be complementary to applied scientific research by demonstrating which combinations of technology and policy are more likely to achieve desired environmental or health impacts.

A number of economic tools are, in fact, available to measure non-market environmental benefits and costs. Feather et al. (1999) summarize the various approaches as follows:(i)

- Averting or defensive expenditures—the measurement of expenditures made by individuals to reduce or negate pollution damages.
- Changes in production costs—observing changes in firm profits, input costs, or output prices due to changes in environmental quality
- Revealed preference—inferring the demand for environmental quality by observing individual behavior. Typically, recreational trips are used to measure the demand for environmental quality.

All of these approaches estimate direct use value of environmental benefits or costs. A fourth measurement approach estimates total value, that is both direct use value and other values such as the value of preserving the environment for future generations or the value of maintaining a resource so that it can be used at some future date. This approach is:

- Stated preference—directly asking individuals either their willingness to pay for changes in environmental quality or asking them to order various scenarios with different levels of prices and environmental quality.

In principle, these methods could be used to evaluate the environmental benefits and costs of agricultural R&D.[13] Obviously, they would add considerable measurement complexity to the analysis and some methods (e.g. the travel cost method based on recreational demand) would not be applicable in many developing country situations. Furthermore, correct interpretation of the signals sent by market behavior must be based on a proper model of the individual choice problem which accurately portrays the substitute or complement relationships and the range of possible individual responses to changes in environmental quality (Freeman, 1985).

Similarly, measuring non-market health benefits in an economic framework can be made by applying concepts such as Quality Adjusted Life Years or Healthy Year Equivalents. However these measures are often obtained through only the fourth method used to measure environmental benefits and costs, the stated preference method. This, in turn, has led many economists studying human health to concentrate primarily on cost-effectiveness measures, rather than the direct measurement of benefits and costs (Hurley, 2000; Dolan, 2000). Thus, incorporation of direct measurements of health benefits and costs of agricultural R&D may be even more difficult than direct measurements of environmental benefits and costs.[14]

Another factor complicating the incorporation of environmental and health benefits into economic analysis is that attribution issues become even more important in this case. As noted elsewhere in this chapter, a large number of factors, ranging well beyond agricultural R&D, influence environmental, health, and other non-market outcomes. In developed countries, application of these non-market measures has traditionally been to evaluate the impact of environmental policy, not the environmental impacts of agricultural R&D.[15] In some cases, it might be best to view policy as the prime instrument for influencing environmental quality, with agricultural R&D potentially providing scientific results that are complementary to policy. Thus, economic benefits or costs that do occur might be rightly attributed primarily to policy, with the value of agricultural R&D lying in the degree to which it enhances environmentally favorable policy.

Despite these many measurement and attribution difficulties, however, over time as research systems mature it is likely that research with direct application to commodities or factors of agricultural production will increasingly be conducted by the private sector. Agricultural research conducted by the public sector will increasingly be called upon to demonstrate its public goods characteristics. This may be one reason agricultural research is now often expected to have a broader range of positive impacts beyond simple increases in agricultural production. As agricultural research is called upon either to mitigate past negative environmental or health impacts, or to provide new, positive benefits in these or other areas, incorporation of non-market impacts into economic analysis will become increasingly important.

9.2.8. 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*. According to Davis et al. (1987), spillover effect is a combination of four effects:price effects from the increased production caused by reduced costs which are captured in the supply and demand framework: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.

The key consideration in the economic analysis of R&D investment is the *technological spillover*; which refers to the spillover technology from one country to another or from one environment to the other. Technological spillovers increase the returns to research and can be spill-ins or spill-outs. Spill-ins refers to situations where a country is adapting a technology developed elsewhere. This reduces the national research costs as well as shortens the time required for developing and disseminating the finished product. The gains from spill-ins are important to virtually all research organizations, but higher in smaller NARS. Spill-outs refer to a situation where the research findings are used by other countries. If one is looking at the costs and benefits from the point of view of the country where technology was developed, then this aspect could be ignored. However, if one is interested in the total benefits occurring to both the country where it was developed as well as the country where it was adopted, then spill-outs are important. Maximizing technological spill-over is the primary economic motive behind regional networking. This aspect is critical in performing impact assessment within the regional network context of many developing countries. The overall effect includes both technological spillover and the research-induced price changes in the various markets.

It has been long recognized that R&D spillovers are both prevalent and important (Griliches 1992; Evenson, 1989). A study that fails to account appropriately for spill-ins will overestimates the benefits from its own research investment.[16] 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.
The meta analysis performed by Alston et al. (2000a) reported that only 12% of the 292 studies in their sample made any allowance for technology spillovers; even fewer allowed for international spillovers. 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.

Davis et al. (1987) 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 agro-ecologies and rural infrastructures ranged from 64 to 82% of total international benefits. Maredia and Byerlee (2000) in analyzing 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. Alston et al. (2000b) measured the impact of research conducted within individual Latin American and Caribbean countries covering edible beans, cassava, maize, potatoes, rice, sorghum, soybeans and wheat concluding 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. Evenson (1989) also concluded that at least for the United States, the locational range of spill-in effects for crop production is lower than for livestock production. Frisvold et al. (2003) showed that 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. Overall increases in net global welfare from U.S. crop improvements were distributed 60% to the United States, 25% to other developed countries, and the remainder to developing and transitional economies.

As noted in sub-chapter 9.1, growth in public funding for international research has slowed over the last twenty years. Thus, understanding the ROR of the CG 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; Pardey et al. 1996; Heisey et al., 2002; Bofu et al., 1996; Fonseca et al., 1996; Johnson and Pachico, 2000; Brennan and Bantilan, 1999; Brennan et al., 2002). The general conclusion is that The estimates of total benefits from varietal improvement research conducted by the CG centers greatly exceed the total research costs and the benefits to particular donor countries (such as Australia and the United States) well exceeded their expenditures on support for international agricultural research (Alston, 2002). Brennan (1986, 1989) reported that 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. 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.[17] 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.

Brennan and Bantilan (1999) and Brennan et al. (2002) took explicit account of the world price impacts in assessing the Australia's benefits from research conducted by ICRISAT and ICARDA. In the case of ICRISAT, research on sorghum, 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 very well summarized by Alston (2002):

- Intra national and international spillovers of public agricultural R&D 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.

Alston (2002) also noted that the estimation of these state, national or multinational impacts is data intensive, difficult, and adds to the measurement problems. However, there can be little doubt that agricultural R&D 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 R&D 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 developed 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 R&D technologies.

Studies of industrial R&D spill-in and pre-invention science spill-in. Evenson (2001) also identified considerable industrial R&D directed towards products sold to and used in the agricultural sector. Agricultural machinery and agricultural chemicals are obvious cases where industrial R&D 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). 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. The studies summarized in Table 9.17 specifically identified pre-invention expenditures and activities as well as industrial spill-ins. It may be noted that these studies report relatively high rates of return and is roughly equal to the social RORs to public agricultural research.

Insert Table 9.18. Economic impact studies:Private sector R&D spill-in and pre-invention science spill-in

9.2.9 Impacts of public sector agricultural R&D investments on poverty.

Several recent IFPRI studies (Fan et al., 2005; 2004a, b, 2000; Fan and Zhang 2004) 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. To assess the impact of public investment on poverty, the number of poor people who would come out of poverty for a fixed investment (e.g., one million shilling or 10,000 yuan) across different sectors was estimated. Similarly 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.

The ranking of the various public sector investments in relation to returns to investment and poverty reduction for the case study countries are presented in table 9.19. In terms of returns to investment, agricultural R&D ranked number one, except for Ethiopia, suggesting this to be the most efficient public sector investment possible. In terms of number of poor people 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. As with the 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).

Insert Table 9.19. Ranking of public investment effects in selected Asian and African countries

However, although economic growth is normally linked to poverty reduction, this is not always so. Over the past 40 years, thanks to AKST investment, per capita world food production has grown by 25%, and food prices in real terms have fallen by 40%. Between the early 1960s and mid-1990s, average cereal yields grew from 1.2 ton to 2.52 ton per hectare in developing countries whilst total cereal production has grown from 420 to 1176 million tons per year. But 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). According to a report launched by FAO (2005d), Sub-Saharan Africa experienced an important growth in the agricultural sector. However, they suggest that additional analysis would be required to understand better who has benefited from this additional growth, and why this growth did not translate into a commensurate improvement of food security. The evidence is that while growth did take place, it did not really lead to improved food security and reduced poverty; the fact remains, however, that it has been possible, during the last decade, to lift agricultural growth at a level above the rate of population growth in the region as a whole, and much above in a few countries. Additional conditions have to be fulfilled in order to reduce poverty by increasing productivity and achieving economical growth. There exist no agreement in the literature as to what kind of technologies would have a 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 benefits the wealthier farmers that brings economical growth, but does not affect poverty. It is also worth noting that poor farmers do not have access to the technologies but also do not participate in the decision process of which technology is the one they need the most. For that reason the technologies developed might not be focused on their requirements, but in the general context of increasing productivity, this may not be their main priority. Recently, some explicit efforts are being made to include the farmers' necessities in the R&D agenda.

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 the specific technology, per se. Technology's role in alleviating poverty is both indirect and partial; technology alone cannot overcome poverty, nor can continued poverty be blamed on improved technology. Effects of improved technology on income distribution across farms with different resource endowments have been ambiguous. It is easy to find cases in which poor farmers with small land holdings have benefited as much as large farms, 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 socio-economic conditions of a particular case rather than the characteristics of the technology per se (Kerr and Kolavalli, 1999). Freebairn (1995) notes that debate about the Green Revolution's distributional impacts are interminable and seemingly irreconcilable. He reviewed 324 papers, about 80% argued that inequity worsened with the green revolution, but significant variations masked this overall figure. He concludes that technology alone cannot solve problems of unequal distribution of productive assets and access to markets and services. Put in another way, technology cannot substitute for structural reforms biased against poor farmers. Innovations in agricultural research alone will not reduce poverty in the absence of poverty-focused policy and action (Gunasena, 2003).

Kerr and Kolavalli (1999) observed that most of the literature tend to link the effect of agricultural research on poverty comes through its effects on agricultural productivity. Research produces new technologies and management practices that increase productivity. However, they argued that this may be too simplistic. Palmer-Jones and Sen (2006) also observed that increasing productivity is not enough to decrease poverty. 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, the suitability of the technology for the rural community. Some of the problems that can be attributed to the development of technologies that could be barriers to reduce poverty are (Kerr and Kolavalli, 1999):

- The adoption of technologies developed somewhere else without the participation of the farmers and without analysis of whether the technology is needed in an specific community; and
- The tendency to homogenize the technologies. Of course it is not profitable to develop technologies for each agroecosystem or for each socioeconomical context. However, the homogenization goes against the diversity, and this is not profitable either.

Other aspects to be considered are the power distribution in the community where the technology is being adopted (a governance issue that will be assessed in sub-chapter 9.3). Of course, this is also affected by the institutional environment, which shows that the increase in productivity itself does not guarantee poverty reduction or income 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 at all common.[18] 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 (Foster, 1998). Although it is by no means certain, 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.

After decades of economic growth, the world is witnessing a dramatic splintering of income equality, both internationally and intra-nationally. Globally, the incomes of the world's richest 1% of earners are equivalent to those of the poorest 57%, and international inequality, which had remained rather stable with the Gini coefficient of world income distribution of about 0.46 between 1950 and 1985, has increased dramatically by 17% (to 0.54) over the past decade (Von Braun, 2003). According to Thirtle et al. (2003) the poverty reduction effect is 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. 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 shows the conditioning of agricultural growth and distributional effects according to Von Braun (2003). He points out that adoption of technologies and success depend on many factors, as for example, land ownership, access to water or availability and efficient use of diverse plant genetic resources. This is in line with the arguments advanced by Hazell (1999) and it points out that at the farm level, prices, access to inputs, 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. 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 inputs and markets is unfair. It is only when these are taken into account that it becomes possible to explain why similar technologies can have very different impacts on the poor in different regions, or at different points in time.

Insert Figure 9.9. The conditioning of agricultural growth and distributional effects (von Braun, 2003)

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).

Chambers (1997) argues that the objective of development is well-being for all, where well-being refers to a good quality of life.[19] It is much broader than wealth and includes the whole range of human experience:social, mental and spiritual as well as material, and each individual may define it differently. 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 it might be needed to measure the link of poverty and agricultural growth by using the human development index, or even developing new ones if necessary, and not only monetary indexes of poverty, such as the number of people living with less than one dollar a day.

To Scoones (2003) 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 centrally about the political economy of agriculture and food in the developing world. With the policy debate cast in these wider terms, there may be more chance of seeing under what conditions technology can indeed benefit the poor. Gunasena (2003) suggests that the research should focus on commodities of the poor, and on areas where the poor is concentrated, rain fed highlands, semi arid tropics and marginal lands. In these areas due to poor eco-physical conditions, even if the land sizes are large the poor will not benefit unless the research is focused on the available resources. This will indicate that research had to be oriented to the natural resources of the region and design research in order to seek ways out of poverty. For the less favored areas where many of the poor farmers live, he points out that it requires long term economic investments in infrastructure, technology, and human development and policy should be geared to such investments. If investments are not made in these areas, the people living in poverty are likely increase further in the future. Without adequate investment in infrastructure, technology and human development these areas are likely to deteriorate further. Gunasena suggests as technologies likely to succeed in these areas to be mixed farming systems; livestock and agroforestry, improved fallows, cover crops, and so on. In all cases marketing institutions need to be developed to support the smallholder 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. Pretty and Hine (2001) performed a sustainable agriculture dataset collection containing information on 208 cases from 52 developing countries. In these projects and initiatives, about 9 million farmers have adopted sustainable agriculture practices and technologies on 29 million hectares. They demonstrated that sustainable agriculture can reduce food poverty mainly upon:(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. According to the authors 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).

All actors seem to agree that participatory approaches are needed. However, 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. Such systems may perpetuate a sense of helplessness among resource-poor farmers who wait in vain for effective technological solutions to come from outside. In this sense, the participatory plant breeding seems to be promising (Almekinders and Eling, 2001). What remains unclear is what role industry would play in this democratization process.

+Gunasena (2003) raises a number of other important issues:

- The evaluation system of researchers does not favor their interest towards the research in favor of poverty reduction.
- Agricultural research policies often do not mention poverty alleviation as a specific target.
- Increased productivity normally leads to reduced food prices, however, Yavapolku et al. (2006) and Minota and Daniels (2005) have shown that rural poverty is linked to international world prices. Rural poverty indirectly depends on AKST achievements.
- Indebted countries, which have to dedicate a substantial part of their GDP to pay the external debt, would show that economical growth does not always means poverty reduction. External debt prevents them from investing it in their internal development.

9.3 Governance of AKST investments:towards a conceptual framework

9.3.1. Demand for improved governance

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

The pressure for such accountability is varied across countries and regions. For example, in developed countries issues of efficiency and pluralism in the research process are becoming more important (Heemskerk and Wennink, 2005). In most Asian and Latin American developing 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). However, in the case of Sub-Saharan Africa, it is the donors who provide up to 75% of the funding for agricultural research in some of these countries who put the pressure for accountability (Herz, 1996). These demands for accountability have resulted in changes on both the sources as well as the mechanisms for funding AKST (as discussed in sub-chapter 9.1.4) and hence the rules and modalities which govern the mobilization and utilization of AKST investments. It is in this context that we analyze the governance of AKST investments in this sub-chapter.

We start with defining governance and to have criteria to judge good governance. This is followed by a discussion of the issues of governance associated with major sources/mechanisms of investments for generation and use of AKST with empirical evidence from different parts of the world. This leads to an outline of the pattern of governance that would prevail in future for mediating investments in AKST.

9.3.2 Defining and judging governance in relation to the investments for AKST

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 the 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 like how efficient or effective is the governance in meeting pre-determined objectives. The theoretical basis for assessing governance is presented in Box 9.4.

Insert **BOX 9.4. On the theoretical framework to analyze governance**

Governance has three core functions:(i) To *identify* what is the `optimal' (or best under the given constraints) 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 rules of the game' that include not only formal rules but also informal ones such as 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. Keeping certain forms of knowledge as public good may be the best way to maximize social gains. There can also be *externalities* in the production and consumption of AKST, which may lead to their over production (consumption) or under production (consumption) depending on whether the externalities are negative or positive. There are *economies of scale and scope as well as network externalities* in the production and dissemination of AKST, which might also require institutional interventions, depending on the circumstances, to minimize social losses. There are pervasive forms of *information failures,* the impact of which can be lessened through certain forms of organizations, regulations and information-disclosure mandates. Societies might have certain distributional objectives such as poverty reduction, helping small farmer, or the provision of certain merit goods and these can also encourage institutional interventions. 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 aim at the following outcomes:

- Societal intervention is designed or carried out only if there is an identifiable problem of market failure. This is needed to allocate public (or societal) resources in areas where uncoordinated actions of the private individuals are inadequate or inappropriate.
- Appropriate non-market institutions are designed to correct identified market failures. The fact that there exists market failure does not by itself justify intervention. The guiding principle should be that the losses due to market failure should be lesser than the cost of correcting such failure. The need to consider the direct and indirect costs of institutional interventions is relevant in this context. In the development and use of technology for each agricultural activity, there can be multiple forms of market failure emerging at different points in the whole process. Thus one institution designed to correct one form of failure may not be appropriate for another.

- Prioritization of appropriate interventions among sectors, or between agricultural research and other interventions in the agricultural sector, considering the likely trade offs. This becomes important if factors other than agricultural growth are the binding constraints to reduce poverty or to enhance economic growth or when, as noted in Garelli (1996), factors other than R&D become binding constraints to enhance agricultural competitiveness. How much allocation for agricultural research is the appropriate level of resource in a country is also a related issue (Tabor et. al, 1998). Since these decisions are taken by a multitude of actors such as international organizations, national and local governments. Each one of them has to take into account the others' likely decisions. For example, for certain technologies, it may be beneficial to depend on international technology transfers rather than attempting domestic research in many poor and small developing countries. This is especially important in the current context of increasing globalization and integration of R&D market, which might make duplication of a great deal of research effort unnecessary (Tabor et al, 1996). However such global dependence may not always be possible for tropical countries whose commodities are unlikely to be cultivated in the developed world.
- Ensuring that institutions, and organizations as well as individuals working within these institutional frameworks serve their intended purpose effectively and efficiently in the current as well as changing situations. The achievement of efficiency in research investments is complex due to problems of economies (some times diseconomies) of scale and scope, which determines the 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 here is to enable the internalization of such efficiency concerns in decision-making. This is achieved through the close alignment of broader social objectives with that of the institutions.
- Following procedures that ensure transparency and accountability for (i) minimizing the likelihood of mistakes and judgmental errors, and (ii) to ensure that broader societal priorities are reflected in the decision-making process, without being captured by the distributional struggles of narrow interest groups. For example it is noted that though domestic agricultural scientists are better informed about the national priorities in agriculture, exclusive dependence on them to make funding decisions can be biased since they have an incentive to maximize the flow of funds to their work (Tabor et al., 1998).

So far we have considered a few outcome-based criteria to judge good governance. There can also be process-based criteria, 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. For example, it is important at the level of a research station, a national research system, at the level of 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 the objectives given to it and within the resource constraints. However, 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. The discussion on governance made here attempts to identify governance issues of concern at multiple levels.

Given that the role of governance is to manage institutions, we need criteria to assess institutions on the basis of governance. These can include:

- *Shaping specific objectives appropriate to socio-economic realities*:A national research system under public sector may be formed or in existence with a broad objective of developing AKST, but its specific objectives are often shaped internally. Whether to work on a particular crop or another technology might be decided within the research system. There is a need to ensure that such specific objectives chosen are in tune with broad socio-economic realities of the time. It is not uncommon to see research stations continue working on crops, which are finding lesser acceptance among farmers due to changed economic situation;
- *Ability to achieve or meet the objectives*:Another characteristic related to the first, is the effectiveness or the ability of the institution to meet the objective, with reasonable assessments of the risks and uncertainty. There are research projects or efforts with specific

objectives, but the mechanisms chosen need not always be designed to meet the objective, even if we take into account the uncertainties involved in any research activity;

- *Ability to assess the demand or the ability to assess the likelihood of creating demand in future*. AKST development has public good characteristics. Since these goods and services are often not exchanged in the market there is no straightforward way of assessing the demand. However this should not lead to a situation in which AKST products are developed without any concern for demand. The whole debate on client responsiveness or the inability of research systems to meet the requirement of farmers (even if they receive AKST research service free of charge) can be reckoned as a reflection of this issue of ability to cater to the actual demand. It is quite possible that the availability of certain technologies or knowledge itself may create demand. However in those cases, the crucial issue is how far the institution is capable of making somewhat reliable estimates of the likely demand in future based on current supply levels of such services;
- *Ability to carry out the assigned tasks in the most economic manner or efficiently:*Even when an institution is effective, it may not be efficient. Thus the institution should enable and encourage organizations and individuals to carry out the assigned tasks efficiently. This would mean producing a given output (or even effort) through the cheapest possible cost, or achieving maximum output for a given input cost. This concern for efficiency is especially important for non-market institutions (such as public provision) since they do not have the obvious incentives/disincentives of the markets (or for-profit firms) to minimize costs and be efficient. The efficiency discussed here should be seen separately from the returns from agricultural research. For certain research activities, the expected ROR can be low. But even this low expected return itself might not be realized if there are institutional inefficiencies. Efficiency can be achieved only through aligning the incentives of actors (organizations and individuals) with the objectives of the institution. An efficient institution need not continue to be so under changing socio-economic conditions. Sometimes path dependence or lock-in occurs by which inefficient institutions continue to persist. The self-perpetuating feedback provided by the organizations, sunk costs, spreading of incorrect models of reality have also been cited as reasons for path dependence. Thus one characteristic required for institutions is the ability to change itself in tune with changing realities. This too requires design of incentives for actors (organizations and individuals) and institutions that encourage them to be in tune with changing economic variables.

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 9.20).

Insert Table 9.20. Guiding questions for institutional assessment on governance

9.3.3 Analyzing the experience of governing AKST investments

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. Improving agricultural productivity was considered to be an important way of enhancing the income of farmers, who had constituted then the majority of population all over the world. The founding of the public research organization was based on an assumption that non-governmental agencies (including private firms and farmers themselves) will not be able to mobilize adequate resources and skills required to generate agricultural research. Farmers were then reckoned generally to be ignorant of the potential of modern AKST and needed to be educated the benefits of new technologies. It was taken that they do 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 land owned by the state). This perception is however now changing.

Public sector investment for AKST was 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 private or not-for-profit sectors to provide agricultural R&D, which mostly falls in the public good domain. It was noted that the task to be achieved by this institutional set up was conceptually simple, which is to acknowledge that agricultural R&D is a public good that must be supplied for the benefit of society as a whole, and all the actors held this same clarity of purpose (Hall et al, 2000). Public funding for AKST has also played an important role in enhancing the awareness of farmers, in creating a wide pool of trained personal, 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. It has been fairly slow in responding to social and economic changes. There have been innumerable cases where research effort fails to meet set objectives, even if we account for the uncertainty inherent in R&D activities. Public organizations were not very successful in taking into account local agro-climatic and socio-economic 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 allocations of resources between capital investments and operating expenditures in the public sector, resulting either in a pool of inadequately trained and equipped personnel or research laboratories without enough money for operation and maintenance.

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 reduces the funds available for the recurring and operating costs (Premchand, 1993). 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. Since public agricultural researchers in many countries face a monopsony market (with one buyer), this tends to reduce the wages and hence the commitment and morale. This is compounded by the rigidities in the formal or public sector labor market operating in many countries. Sometimes non-agriculture motives such as prestige and building monuments drive the establishment of research facilities.

There have been cases of misallocation of public resources between agricultural research and other activities, between research and extension and also in research between different crops. Such considerations can also lead to the spreading of spending too thinly across commodities, regions and research themes. Apart from these issues of allocative inefficiency, there can also be issues of simple or x-inefficiency 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, natural resources) and technologies even when farmers move out of them due to economic reasons. The incentives of individuals within these organizations are rarely in tune with the stated objectives of their organizations. In some cases the public sector scientists do not command support and respect from local constituencies including policy makers and smallholder farmers in several developing countries (Rukuni et al., 1998, Anadajayasekeram and Rukuni, 1999). Studies have also shown that returns to public sector agricultural extension became low due to the multitude of non-extension duties, and that these extension agents not being the main sources of technical information for farmers. Isinika and Mdoe (2001) show that the government extension officers spent increasingly more time on administrative duties and doing very little actual extension work.

Attempts to reform public research started in the eighties when participatory research was advocated. This was to make public research organization more responsive to the requirements of farmers, especially those poor people, and living in resource-poor areas. It must be noted that lack of understanding of the requirements of farmers or clients in general is a problem not only in itself but also has a negative impact on effectiveness and efficiency of research output as well. Along with the advocacy for participatory research, there has been an increasing role for non-governmental organizations in agricultural research and/or extension (Kaimowitz, 1993). There may have been some successes through such participatory research models, but the overall experience seems to be not that exciting. One reason for this could be that this reform has left untouched the structure of public research organizations. The channels of priority setting do not correspond to the funding channel, in other words, money is coming from sources other than those setting the research priorities (Hartwich and von Oppen, 2000). It can also be that the incentives of the individuals working within research organizations were also not adequately oriented to participatory research. It is the actual incentives that matter and not the proclaimed ones. These incentives include not merely additional money but also additional facilities to carry out participatory research. Incentives can also be intangible ones like the joy derived from working with farmers or rural people, if people are attuned to such things. It was unrealistic to expect that the involvement of farmers through participatory process would usher in changes in public system, overcoming the existing structural constraints and incentive problems.

The national public research organizations have also responded to these criticisms 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 developed world. There has also been decentralization of research and extension systems in developing countries including Uganda, Tanzania, Kenya, Zambia and Ethiopia and Zimbabwe (Anandajayasekeram and Rukuni, 1999). In Zimbabwe, the Agricultural Research Council focuses on policy and funding issues, while the execution of research is carried by the Ministry of Agriculture, universities, farmer organizations and other private sector actors (Rukuni et al., 1998). Likewise the Indian Council of Agricultural Research (ICAR) has been restructured to allow headquarters to focus on policy and funding of research while execution has been decentralized to organizations operating within the ICAR umbrella (Byerlee, 1998). Similar examples of more pluralism in AKST systems have also been documented for various Africa and Latin America (Shao, 1996, Echeverria, 1998; Byerlee, 1998, Heemskerk and Wennink, 2005). However, the experience in this regard in different countries is mixed. Research practices, administrative and financial procedures of national research systems have not witnessed any major change in a number of countries State research stations have had only limited institutional changes by the reforms. On the other hand, Venezian and Muchnik (1994) note that reforming compensation in the national agricultural system of Chile, made public research sector more attractive to talented agricultural researchers.

The allocation of resources for research in public system, though ideally be driven by considerations of social welfare, is determined in reality by the political economy. By this we mean the struggle between the interests of different sections of society (social groups, regions, growers of specific crops, gender), and also who dominates in the decision-making in a given context. Evidence from different parts of the world indicates the influence of such political-economy factors in the allocation of resources for agricultural research. Rose-Ackerman and Evenson (1985) build on previous studies on how research and extension spending is linked to the political effectiveness of farm interests. Swinnen et al. (2000) note based on a study of 37 countries that structural changes in the economy have important effects on the political incentives to invest in public agricultural research. Law et al. (2004) document how special grants program of USDA have become vehicle for pork-barrel politics in United States, and the difficulty in changing the status quo.

Thus even when agricultural research provide higher returns or has the potential to reduce poverty, it need not get enough investments in the public allocation of resources. Sometimes ideological considerations lead to high priority being given to certain crops and thus making investments economically inappropriate. Perceived notions of food security in certain states of India have led to excessive research investments on food crops even when the region is appropriate for, and hence farmers adopt, diversified commercial crops (Santhakumar and Rajagopalan, 1995; Santhakumar et al., 1995). An area where political economy influences research investments and outcomes is with regard to gender. This manifests in certain situations inadequate investment in research on crops cultivated by women (homestead vegetables) or technologies to reduce the drudgery of female agricultural workers. In certain other situations, new technologies produced through research lead to the displacement of women workers. Moreover as noted in the case of using ICT (Odame et al, 2002) with regard to agriculture, the access of women to these technologies may be limited because of the reduced physical access to resources and infrastructure, social and cultural norms, education and skills, and poverty and financial constraints.

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 altruist considerations
- Correction of international market failure or the provision of international public goods
- 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 to 60 years. The CGIAR institutions as well as other international AKST research organizations, working in collaboration with national partners have contributed to the Green Revolution and to the sharp increase in food grain production in many countries.[22]. Some would argue that international donors might have considered the persistence of poverty in poorer countries as a threat to themselves, and this has encouraged them to make proactive steps to enhance food production through investing in AKST.

Though this 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 any way 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 (Byerlee, 1998). 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 expenditures, such as between capital and recurring costs, and also for compensation need not adequately reflect the domestic opportunity cost of the resources, and this can create distortions. There have been instances where external aid has compounded the inefficiencies in the investment decisions for AKST in developing countries. As noted by Tollini (1998), the risk of bad investment goes up when grants are easily had. Thus what is important is to note that even altruist based international funding need not always be a boon to developing countries, and there is a need to be sensitive to the possible distortions that can be created in domestic economies and institutions.

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 failure in this regard. There can be international negative externalities, which need action at the international level, but more interestingly there maybe cases where it would be efficient to take action by the international community to address certain problems within the developing countries. Taking the recent example of bird flu, even if the interest in the developed world is to protect itself, financing some activities in developing world would be a more effective and efficient strategy rather than spending money only on protective activities within the developed world. Thus there are cases of international negative externalities that would encourage international donors to make investments in AKST within the developing world. Similar arguments apply for international public goods. Certain technologies or technology generation systems themselves can be seen as international public goods. Here, though the ideal strategy would be for the developed and developing world to pool their resources together, but there are coordination problems in bringing everybody together. Moreover, the severity of lacking such public goods perceived in the developed world would encourage them to take proactive steps, whereas developing countries who face other more pressing problems would give low priority. How far the investments in AKST 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 reductioning of global production has also driven developed countries, multinational firms and multilateral agencies to make investments in AKST in developing countries. These, however, raise a number of issues:(i) Trade and non-trade barriers (and associated transaction cost existing all over the world) 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 from different quarters during the last decade. It has been noted that the incentives of the personnel in these agencies are 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 affected the efficiency of the investments in AKST made by multilateral funding agencies in the developing countries is an issue that needs to be analyzed.

*Competitive funding***.** 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. This mechanism;

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

However, competitive funds have the disadvantage of having high transaction cost (Echeverría, 1998). As noted by Huffman and Johnson (2001), competitive grants take scientists' time (funded through core funding) for preparation of research proposals, and evaluation. 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 building 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 developed countries.[23]

Commodity boards or growers associations. The growing role of commodity boards, producer-funded or growers' associations, in research is also a related development. 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. There have been arguments as in the case of Tea in India (Muliyar, 1983) that 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. Similarly if research is carried out by the commodity boards having 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 governments (Narayana, 1992). It was noted that acceptable ratios of personnel/operations cost prevail in coffee and tea research, which is financed by a cess on these commodities in Kenya. However, in Kenya, there are also cases in which growers associations become politicized and hence being less accountable to the growers (Kangasniem, 2002). In Zimbabwe, the Tobacco Research Board (TRB) is an industry dominated statutory body, which has been managing research on this crop. After phasing out subsidies in the

1990s, now tobacco research is entirely funded by the industry. Though TRB is a para-statal but for the most part it has been able to avoid the problems affecting Zimbabwe's public sector. It is not overstaffed; it has sufficient operating funds to keep employees productive and pays competitive salaries that are substantially higher than those paid by the government agricultural research services, therefore retaining good researchers and demanding good standards of performance.

However one should be concerned about the producers' associations or commodity boards focusing on the sole benefit to producers and thereby 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 sustain in a more market-determined situation. One can also see that producer organizations may not be the best suppliers of research services except for adaptive on-farm research (Echeverria, et al 1996). This may provide a justification for continuation of public funding for basic and strategic research even in developed countries. Moreover for crops such as rice or wheat the concept of growers' association becomes unmanageable due to their large number of cultivators and would have problems that are similar to those of publicly owned research. Additionally, to what extent the small farmers (those who need more help in terms of the MDG) are represented by these associations remains unclear and depends on the commodity and the countries.

Private research. 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 private sector has developed in AKST investments. The structural adjustment policies implemented in many developing countries,[20] the global changes in trade regime and developments in biotechnologies, have also facilitated this transition.[21] 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 private sector to some extent fills the gap between technology generation and extension that existed in public research model. There has been an increasing involvement of private sector in agricultural extension too (Umali and Schwartz, 1994).

There are variations between countries and regions in terms of the contribution of private sector in agriculture research. Though private sector has acquired a dominant role in this regard in

OECD countries, their share in many developing countries continues to remain insignificant. Not surprisingly, McIntire (1998) argues that there may be a linkage between national income of the countries and the role of the private sector in agricultural research. For example, countries with per capita income of less than US$1,000 do not have any significant private research. But the lack of significant private research can also be due to the legal and administrative problems in many countries (Ahmed and Nagy, 2001) and need not be due to the unwillingness on the part of private firms.[24] There are also 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) (see also Box 9.5).

Insert BOX 9.5. A new public-private partnership paradigm for African agriculture:The African Agricultural Technology Foundation

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. In the case of Africa, some of the experiences with the alternative options are summarized in Box 9.6.

Insert Box 9.6. Experience of new funding options in African countries

9.3.4 Governance of AKST and the changes in larger institutional environment

So far we have considered only the institutions directly governing AKST investments. However the broader institutional environment encompassing the ownership of or 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 institutions, national policies regarding 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 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 developing in many developing countries, and this will have a bearing on how AKST is generated and used, 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 nations and the world. The market development in developing countries,[25] changes in world trade regime,[26] structural adjustment policies in many countries, and others are going to influence not only natural resource management but also investments in AKSTD.

In addition to these institutions, the way human consumption especially that of food and agricultural commodities changes in 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, and this is attempted in subchapter 9.4. However one probable scenario on the governance of AKST in the near future is outlined below.

9.3.5 Outline of the future roles of governance and institutional structure

In many developing countries, domestic private sector may continue to play only a small role in the near future. Even in developed countries, the new set of research instruments is not going to replace conventional public research model. It is envisaged that there will be a combination of public and private investments with the latter increasing overtime. 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 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 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 (for example drought prone) areas 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 developed 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 non-profit oriented investments.

However it is very likely that there is more and more rethinking on the specific roles of (and on the specific instruments to be used by) 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 system 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 (Pray, 1998). 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.

9.4 Investment options

The goal of this international assessment of AKST is to provide policy makers with research investment options for meeting the following development and sustainability goals: decreased hunger and poverty, improved nutrition and health, sustainable economic development, enhanced livelihoods and equity, and environmental sustainability.

Previous chapters (6 through 8) have provided policy options for enhancing the impact of AKST, strengthening capacity of AKST, and improving policy and regulatory environments for private sector research and technology transfer.

This subchapter focuses on the research investment options of governments, international organizations, and foundations that support AKST. The questions that these organizations would like answered include:

a. How much should governments invest in AKST versus other public goods?
b. In what? How should research resources be allocated?
    i. Commodities
    ii. Where? e.g. less favored land, small poor countries
    iii. Labor using, land saving, or water saving technologies?

c. How?
    i. Which disciplines?
        1. Traditional plant breeding, soil science, etc
        2. Farm management research and extension e.g. Integrated Pest Management.
        3. Social science research
    ii. Which components of AKST need most resources: basic research, applied research, extension, farmer education, enhancing indigenous knowledge?
    iii. Which institutions – international centers, Regional research, NARSs, universities, NGOs, public private partnerships.

The answers to these questions should be based on multiple criteria – Social rates of return to research, impact on poverty and hunger, impact on human health and impact on the environment. Then societies and policy makers who place more emphasis on poverty reduction rather than economic development or environmental impacts could place more weight on the research investments that reduce poverty than societies that favor improving the environment.

Formal priority-setting methods, including those based on rates of returns studies, are rarely used in practice to set research priorities, and formal multi-criteria techniques for research resource allocation are used even less. They are not used because they are expensive, time consuming, and some factors are almost impossible to quantify. The impact of agricultural research on the environment, health, and hunger has been particularly difficult to measure. As a result, most of the studies that we were able to assess and base our policy options on are those of the rates-of-return type.

The purpose of this sub-chapter is to use the findings of preceding sub-chapters, the baseline projections and projections based on some policy options to develop research policy options that could reduce poverty and hunger in a sustainable way. This task is broken down into three components. (i) The next sub-chapter (9.4.2) briefly discusses some previous attempts at setting research priorities making use of formal priority setting methods – particularly priority setting attempts that use multiple criteria, (ii) the next sub-chapter (9.4.3) describes available evidence from other parts of this assessment of the impact of AKST on economic development, poverty, health, and the environment, and (iii) the final sub-chapter (9.4.4) provides research investment options for policy makers on how much to invest in AKST and how to allocate that investment to some key commodities and institutions. This subchapter does not discuss allocating resource between different disciplines and components of AKST since that is covered in Chapters 7 and 8 of this report.

9.4.1 Criteria for research investments

Vernon Ruttan in his book on research policy (Ruttan 1982:263) pointed out that ….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?

One of the most comprehensive studies of research resource allocation – Alston, Norton and Pardey (1995) – spells out the methods for allocating research resources that combine information from scientists, technicians and other experts on the expected output of science, their probability of success and possibly timelines with information from economists and other social scientists on what the potential economic and social payoff would be if this research is successful. However, based on a recent assessment of agricultural research in nine developing countries, Pardey, Alston, and Piggott (2006, p. 370) concluded that:

> In recent years, economists have developed formal models for the ex ante evaluation of research projects to assist decision makers in allocating research funds. These models are being used increasingly in more developed countries, but they seem not to be used on any systematic basis in the case-study countries (except as a condition of donor funding). Similarly, the allocation of research funds according to clearly articulated research priorities – as happens in many developed countries – is less common in the case-study countries.

Measures of how much research can reduce hunger and poverty or improve the environment is used even less by public sector research institutions (and never in the for-profit private sector) to allocate research resources. The international centers of the CGIAR, which have as their mandate the reduction of hunger, is one of the few organizations explicitly to pay attention to hunger and poverty in allocating their funding. One result of this policy has been the shift of CGIAR resources towards Africa over the years. The CG is also one of the few public research organizations that have shifted significant shares of research investment into resource management research and research to encourage the supply of ecosystem services. Over the past twenty years it has, for instance, established new centers on water management, biodiversity preservation, agroforestry, and forest policy.

Combining ex ante rate-of-return models with distributional concerns such as poverty reduction, concerns for health-related outcomes, and concerns for environmental dimensions of agricultural practice into a holistic priority-setting system is, contrary to what might be interpreted from the penultimate paragraph in subchapter 9.2.3, rarely done in the practical world of research resource allocation analysis and, in accord with predominant contemporary practice, we do not attempt to use any formal way of putting all these measures together in this report. Rather we lay out the information available on the priorities implied by the different criteria so that policy makers can see the synergies and tradeoffs implied by using different criteria. Our cautious approach reflects the instructive discussion by Alston and others (1995, pp. 464-94) of well-intentioned but oft misguided attempts to deal with such multicriteria formulations of research priorities. In their still-cogent review of methods based on scoring models, those authors speak of the procedures as being very tricky, requiring great caution, and too often producing effectively meaningless and nonsensical results, so there are definitely methodological challenges in such work yet to be satisfactorily dealt with. 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 NARSs, the task of developing the needed capacity to address aspects such as environmental economic assessment of NRM consequences of agricultural technology is a large one (Crosson and Anderson 1993), still not yet adequately developed in an era of profound underfunding of research, at local, national and regional levels. But there has been some recent encouraging progress on both method and human capacity dimensions, for instance at the regional level in SSA (e.g., Mutangaduraa and Norton (1999) in Zimbabwe and Omamo and others (2006) for the ASARECA countries of East and Central Africa).

9.4.2 Review of evidence of the impact AKST on economic growth (ROR), poverty, hunger, health and the environment

Evidence of returns to research from sector studies. The data on public and private research investments in sub-chapter 9.1 and the rates of return studies in 9.2 suggest that currently there is serious underinvestment in AKST in most developing countries. A number of studies reported in subchapter 9.2 calculated or compiled the social returns to aggregate (as opposed to commodity or project specific) public research (see Tables 9.8, 9.9, and 9.10). Most of these studies reported fairly high returns to the aggregate investments. A study by Thirtle, Lin and Piesse (2003) put the mean rate of return for African countries at 22%, of Asia countries at 26% but of Latin America at -6%. A study by Evenson and Rosegrant (2003) found the IRRs for the NARSs ranged between 9 and 31% and IARC programs had very high IRRs which ranged between 39 and 165%. The lowest IRR for national research was observed for sub-Saharan Africa (9%), while those elsewhere were higher; Latin America 31%, Asia 33%, and West Asia-North Africa 22%. Finally, Evenson (2001) analyzed a number of economic impact studies evaluating the contribution of agricultural research and extension programs. The estimated median IRR estimates for agricultural research for Latin America, Asia and Africa are 47%, 67%, and 37%, respectively. It was also noted that the benefit exceeded cost in Sub-Saharan Africa almost 15 years later than was the case for Latin America and Asia, causing the low IRR. Both meta studies found that returns were high in all regions of the world.

All of the meta-analyses find that RORs regionally averaged tended to be highest in Asia and lowest in Africa and Latin America. The Evenson and Alston et al. studies find Sub Saharan Africa has lowest returns but Thirtle et al. (2003) found that IRRs in Africa were almost as high as in Asia, and that Latin America had the lowest returns. The important fact is that, on average, the rates of returns in Africa were high and there were many cases of very high returns to research in specific countries and projects in Africa.

Are these returns higher than other public investments that governments could make? Studies by IFPRI and economists from seven countries in Asia and Africa (Fan et al. (2005; 2004a, b, c; 2000) (Table 10.18)) show that the returns to agricultural research are also high relative to other public investments such as in irrigation, roads, electricity, and other government programs. Agricultural research had the highest returns in six of the seven countries. The other component of AKST in these studies was primary education. It ranked second or third in terms of rates of return in all seven countries.

Returns to research by Commodities and Factor savings. The rates of return studies in sub-chapter 9-2 show that both the research to increase agricultural productivity and the research to improve ecosystems services and sustainable agriculture can produce high returns. Table 9.20 summarized the results of the two major meta studies of research that are described in sub-chapter 9.2. Most of the studies in the crops and livestock categories are germplasm-enhancement studies and show very high rates of return.

The studies that measure returns to research on sustainable agriculture are quite limited in number, but mainly fit into the resource management category in Table 9.23. The median economic returns in this category were 17%, which is a high rate of return for a government investment although considerably smaller than the returns from the productivity increasing investments. Since these meta studies were done, the CGIAR commissioned a number of studies on natural resource management research. These studies found that it is inherently difficult to measure some of the most important impacts of NRM research (CGIAR 2005; Zilberman and Waibel 2006) but that some of NRM projects had high RORs that were comparable to returns from crop-improvement research.

The studies that try to estimate the separate impacts of different components of AKST often compare research and extension. Returns from both of these activities are high (Table 9.10) but research generally has higher returns than extension. Evenson (2001) also discusses the limited number of studies on strategic or pre-invention research, which he finds to have higher returns than applied research and private research, which has social returns that are of about the same size as those for applied research.

Insert Table 9.20. Summary of the meta-analysis of rates of return to research

Impact of AKST on Poverty. The studies by Fan et al (2005; 2004a, b, c; 2000) show that agricultural research can also be an important tool in reducing poverty. Agricultural research ranked first or second among public investments in terms of its ability to reduce poverty in the six Asian and African countries that they studies (Table 10.18). Primary education was first, second or third in poverty alleviation in 5 of the 6 countries where poverty alleviation was measured. Research in the major grain crops and the international center's research have been shown to be major contributors to reducing poverty and hunger, as synthesized by Lipton (2001) and others. Lipton makes the case that the Green Revolution in major food crops such as rice, wheat, and maize both reduced the price of basic food grains by increasing total factor productivity, and increased the demand for labor. The combination of these factors increased the income of the poorest groups in societies where labor was abundant. Other types of agricultural research such as that to improve intensive livestock production or plantation agriculture are often more likely to increase income inequality within the rural sector by differentially boosting the income of wealthier farmers. Research alone can seldom reduce poverty and has to be accompanied by other pro-poor policies, such as access to natural resources, equity of access to technology, good governance practices, local market development, etc.

Impact on Environment and Health. Examples from subchapter 9.2 of the environmental impact of one type of research – productivity increasing research – are shown in the third column Table 9.21.   Many but not all of the examples report evidence of negative impacts of the productivity enhancing technology – e.g., biodiversity is decreased when new lands are cultivated; water pollution increases due to overuse of pesticides and inorganic fertilizer, and overproduction of animal manure; salinity and alkalinity increase through insufficient irrigation and poor drainage; shrimp cultivation replaces mangroves, etc. – but they have also in some cases slowed the destructions of rainforests through increased productivity on traditional agricultural lands.

The last two columns in the table point out some of the AKST activities that can mitigate the negative impacts of pollution. First, research to develop management practices, technologies, and policies that reduce the ecological footprint of agriculture, such as reducing agricultures' use of fossil fuels, pesticides, and fertilizer. This would include AKST to develop management practices such as zero-tillage systems to reduce use of fossil fuels for land preparation, 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. 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 ethanol from sources such as sugarcane or biomass that do not compete strongly with food production. There is some evidence that research in this area can provide a good economic rate of return, and the rates of return are likely to rise as more governments put policies in place that reward farmers for the provision of these services (e.g., Hazell and Pachauri 2006).

The studies of the rates of return to research that improves the management of resources (Zilberman and Waibel, 2006) are difficult to do, but they show that these investments can provide a reasonable return to the investment (although lower than for commodity research).

Negative health impacts of some agricultural technologies have been documented in case studies (Pingali and Rola in the Philippines) but the aggregate size of the problem has rarely been quantified. The negative impacts of pesticides are perhaps the best documented but even in this area the estimates of how many people are poisoned while working with pesticides (as opposed to using them, say, to commit suicide) vary widely. The topics of pesticide poisoning of farmers and farm laborers, and problems of pesticide residues on food, still warrant much more study to gain insights for policy and investment.

Insert Table 9.21 Environmental impacts of productivity increasing research and mitigation research

9.4.3 Research investment options

The ideal social planner would be able to rank research investments by their expected contribution to economic growth, poverty reduction, improved health, and environmental services; then she would solicit weights from society based on the relative value society places on economic growth, poverty reduction, improved health, and environmental services. Each country will have different weights based on their available resources, their culture, their institutions and there technology. Based on chapters 2, 3, 5, and 6 and the Key Messages the following assumptions were developed and are the basis for the investment options that follow.

Demand for agriculture

1. Demand for agricultural products will continue to grow rapidly driven primarily by income growth, but also by population growth, and new uses for agriculture such as substitutes for fossil fuels
2. Demand for ecosystems services from agriculture will also grow with income growth and with further evidence of the impacts of global climate change

Constraints on increasing agricultural supply

1. Land will continue to be the major resource constraint on the expansion of agricultural production
2. Water will be an increasingly important constraint in the future
3. The supply of clean air and fossil fuels will also become important constraints
4. Increased intensity of agricultural production will increase agricultural disease and pest problems

The potential of AKST to solve these problems (based on key messages of Chapter 6)

1. Advances in basic biological knowledge such as genomics and proteomics, nanotechnology, information and communication technologies, and other new advances in AKST will create major new opportunities for increasing agricultural production, ecosystem services, and health benefits from agriculture.
2. Emerging knowledge of agroecological processes and synergies, and the application of resultant technologies, will play a crucial role in future AKST response
3. AKST can be harnessed to reduce GHG emissions from agriculture, to increase carbon sinks, to mitigate climate-related production risks and to adapt agriculture to climate change.

More public investment in AKST can meet economic growth, poverty reduction, ecosystems services, and health goals. LDCs need to invest more public sector resources into research. To reach the OECD level LDCs would have to invest $2 in agricultural research for every $100 of Ag GDP the public sector. This implies a major increase in investment in agricultural research from the current level of 0.5% in LDCs. This quadrupling of research intensity may not be needed particularly in large countries where there are opportunities for taking advantage of economies of scale in research on major crops (Jin et al., 2005), but major investments in public research are necessary. A few developing countries such as China are making investments that could lead to 1% level by the end of this decade.

The rates of return studies summarized above support this policy option. These studies show that the returns to public research are high. As reported above the IFPRI 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. In the same studies 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. However, evidence shows that research alone can not reduce poverty as has been discussed in 9.2, and AKST has to be accompanied by other pro-poor policies, such as access to natural resources, equity of distribution, good governance practices, local market development, etc.

Investments in AKST can also be productive in reducing some of the negative externalities from productivity enhancing technology (Table 9.21; chapters 3 and 6). AKST can reduce inefficient and harmful pesticide use through IPM and biological pest control measures such as plant and animal varieties that are resistant to pests.

In addition the assumptions mentioned in the introduction to subchapter 9.4.4 suggest that returns will stay high. First, the demand for agricultural products will continue to grow rapidly in the next 50 years, pushed upward by increased per capita incomes, continued population growth, and increased industrial uses such as biofuels. Second, resources which are now used to produce agricultural products will be increasingly in short supply - - water, land, and clean air. Third, basic science is moving rapidly ahead creating new opportunities for applied science and technology, which will also increase returns to research.

Allocation of AKST resources. Table 9.22 shows the summaries of rates of return to research for different commodities, resource management, and different types of institutions, matched up with some examples of negative and positive impacts of these types of research on the environment, health, and poverty reduction. This allows policy makers to see how different choices of investments in AKST on specific commodities or types of institutions are more or less effective in reaching certain goals. For example the row on wheat shows that the rates of return to wheat research have been high, but irrigated wheat in poorly drained regions has led to salinity problems, pesticide use is limited so little negative impact of pesticides while reduced prices of wheat has increased consumption of wheat by the poor improving their health. Improved wheat technologies during the green revolution period in South Asia increased demand for labor and thus the incomes of the poor.

An example of where productivity increasing research can have a negative impact on reaching other development goals is research to increase the productivity of intensive livestock production. It has high rates of returns but major negative environmental through water and air pollution, and negative health impacts through E. coli. At the same time it can have positive health impacts through dramatic declines in the price of meat and poultry which provides more people with protein and other needed nutrients

Insert Table 9.22. Summary of impacts of productivity increasing technology – economic returns, externalities and spillovers

Investments meeting multiple criteria.

Public investments in AKST to increase the productivity of basic food crops such as wheat, rice and maize in developing countries must continue to be high priority. Tables 9.8 and 9.10 as summarized in 9.22 show that the returns to the investment in research have been very high. In addition as describe in the introduction to this subchapter they also made a major contribution poverty and health goals. They have contributed to some environmental goals – reducing pressure on the biodiversity in forests – while leading to some negative environment impacts in some areas – increased pesticides and salinity.

AKST resources must be invested in developing technology and management systems that save on the use of scarce resources such as land, water, and in the future, fossil fuels. The major resource constraint on increasing agricultural production in the future will continue to be agricultural land. Governments, international organizations and private firms have responded by developing more intensive agriculture. In the future AKST must focus on increasing output per unit of land through technology and management practices. Evidence from the rates of return studies show that rates of return to land saving research is high, although there are only a limited number of studies on returns to land management research.

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 starting to be reallocated into water-saving techniques, improved policies and management techniques. A few examples of water saving research which were evaluated by SPIA has had high returns (Zilberman and Waibel, 2006), and some of the research on drought tolerant crops 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 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. There is little evidence yet from the rates of return literature of high returns. 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 inform farmers how they may best reduce agricultural use of this resource.

The environmental and health consequences of these types of research can be high. More efficient use of current crop land reduces pressure to cut down forests and destroy biological diversity. More efficient use of crop land is often labor using which increases demand for services of the poor in economies with abundant labor. More efficient use of water can reduce waterlogging and salinity which can improve long term productivity of land and reduce environmental problems, Reduction in fossil fuels can reduce global warming, reduce the use of some labor-saving machines, and again increase demand for labor reducing poverty in some economies.

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 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 livestock production methods; more labor use, which could reduce poverty; and positively improve human health. This is an area in which public and private collaboration is essential.

Pre-invention, strategic, and basic research can be justified in many countries As chapter 6 indicates advances in basic biological knowledge such as genomics and proteomics, nanotechnology, information and communication technologies, and other new advances in AKST will create major new opportunities for meeting development and sustainability goals. Emerging knowledge of agroecological processes and synergies, and the application of resultant technologies, will play a crucial role in future AKST investments. This new knowledge can be applied to develop technologies that improve agricultural production, mitigate climate change, improve health or reduce poverty. Thus, it is not inherently productivity increasing or polluting.

For many advanced developing countries and OECD countries inventions in this strategic or pre-invention research is a good investment because of the technological opportunities that it opens up. 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 (Tables 9.10 and 9.17). Evenson (2001) finds that the limited number of studies on strategic or pre-invention research has higher returns than applied research.

Investments favored by one criterion

More public investment in AKST to help agriculture provide ecosystem services such as reduced greenhouse gas emissions, reduced water pollution, slowing the loss of biodiversity, and maintenance of livelihoods. These investments will be of three types. First, research to develop management practices, technologies, and policies that reduce the ecological footprint of agriculture, such as reducing agricultures' use of fossil fuels, pesticides, and fertilizer. This would include AKST 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.

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 ethanol from sources such as sugarcane or biomass that do not compete strongly with food production. There is some evidence that research in this area can provide a good economic rate of return, and the rates of return are likely to rise as more governments put policies in place that reward farmers for the provision of these services. Third, research to support indigenous knowledge to improve rural livelihoods will be required. This knowledge has been neglected but research and management systems based on this knowledge has been shown to have positive ecological and economical impacts.

This may be an area of AKST which has lower returns to research than other types of research – so far there is limited empirical evidence on returns to this research but the returns appear to be lower (see Table 9.22). In addition, some of the agricultural technologies to provide these ecosystem services can be designed to use the assets of the poor, such as labor in labor-abundant economies.

A major increase in private sector research will be needed to increase agricultural productivity growth for developing countries. Private sector investment in R&D in developing countries lags far behind the OECD countries both in absolute amounts and in research intensity than public sector research (Table 9.2 and Figure 9.4). There is less than $1 billion spent on private R&D in developing countries compared to $12 billion in OECD countries (see Table 9.2). There has been concern among policy makers in developing countries that private sector research primarily benefits the private sector itself. However, economic logic suggests that farmers will not adopt technology from the private sector unless they believe they will benefit from it, and the available empirical studies unanimously shows that they do – in most cases more than industry (Pray et al., 1991; Pray and Naseem, 2006; Table 9.17). Substantial benefits have accrued to farmers and consumers from private sector research as shown by the fact that median rate of return to research by private in the studies analyzed by Evenson (2001) was 50%. 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.

An indirect benefit of increased private sector research is that the public sector can shift its research resource from crops like hybrid corn and commercial poultry production, which the private sector will do, to the provision of public goods such as technology to reduce environmental problems, improve health and reduce poverty.

Private sector research has providing substantial benefits to farmers and consumers in developing countries. However, private companies if they want to stay in existence must focus on providing market goods to people who can pay for them. Thus, they are going to provide less than optimal levels of public goods such as basic research and are not going to be concerned about some environmental externalities except as it affects their public image. Nor will they focus optimal amounts of attention on providing food and other goods to the poor who do not have much purchasing power.

To induce more private research, governments will have to invest in developing an enabling business environment for private investment as described in the subchapter Determinants of private research in 9.1 and in Chapter 8. The components of an enabling business environment includes a functioning system for protecting intellectual property rights, the ability to enforce contracts, a stable regulatory environment, functioning markets for agricultural inputs and outputs, etc. To make such government investments politically acceptable may require environmental and food safety regulations and liability laws that force firms to internalize at least some negative externalities from the technologies they introduce. In addition, industrial policies that limit monopoly power may also be politically important.

Funders of AKST that emphasize poverty reduction and environmental services will need to invest in public NARS and International Agricultural Research Centers. The last four rows of Table 9.19 focus on different types of AKST institutions – NARS in developing countries, International Agricultural Research Centers of the CGIAR, and private research. The NARS research has generally had high returns. Some of the technology that they have introduced that has had the highest returns – the Green Revolution technology in major field crops – has had some negative consequences associated with it but has generally been pro-poor in developing countries. If public sector AKST institutions can be made more responsive to environmental concerns and the needs of the poor as suggested by the subchapter 9.3, they could be more pro-poor and pro – environment in the future. Research by the International Centers has in general had even higher returns than research by the NARS. While the original green revolution technology which the original CGIAR centers – IRRI and CIMMYT - helped produce had some negative environmental impacts, much of the research that has been done in recent years has been focused on mitigating these impacts - for example crop breeding to produce varieties that resistant to pests, water management research and policy research to reduce over watering and reduce salinity. In addition new centers such as CIFOR have been added to explicitly address environmental issues. In addition the centers are explicitly focused on reducing hunger and poverty and much of their research has done that.

A portfolio of Investments in AKST to meet multiple goals. If as has been argued in 9.4.4, a large infusion of public funding is needed in AKST, then a coalition of interest groups will be needed to lobby for this funding. This suggests that policy makers and advocates for AKST activities that increase agricultural productivity, ecosystem services, improve 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 should be attractive to these different groups but perhaps more importantly research administrators and advocates need to develop a portfolio of AKST projects which encourage productivity growth but also provide ecosystem services, improve health and reduce poverty.

As the AKST investment alternatives listed above indicate, some research investments can meet multiple goals. Other investments primarily meet one goal but still play a valuable role and should not be eliminated because it does 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 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.

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; such as basic research and meeting other social goals such as improving the environment or developing technology for resource poor farmers. Thus, many countries could reduce their public research on improving the productivity hybrid maize and shift those resources into productivity enhancing research on cassava or open pollinated varieties of maize which poor people grow. Or the resources could be shifted into fertilizer and pest management to reduce overuse of chemicals that create pollution and can harm human health.

Another possible strategy would be to fund plant breeding to increase yields, but to do so only when it is accompanied by breeding for durable resistance to pests and disease and research on IPM in these crops. Much of this is already done, but in many cases the bulk of the resources go to productivity increase with environmental consequences left behind.

Policy makers to who wish to reduce poverty and increase productivity can also develop and an appropriate AKST portfolio. They can make major investments in research to increase the productivity of major crops of the country but ensure that an important share of the investments go to major subsistence crops such as rice, wheat, and other basic staples that are grown and/or consumed by the poor. They can allocate the productivity-increasing research to 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. In addition they can support research programs and public-private partnership which (i) adapt scientific discoveries from developed countries and import technology from them that increases productivity for poor farmers; and (ii) transfer technology from neighboring countries, which may have developed technology that is more appropriate for poor farmers in developing countries. These technologies can flow through multinational corporations, through local private firms, and through public sector research systems and their regional networks, presently severely under-funded.

Countries could also develop a portfolio which combines investments in AKST on ecosystem preservation and enhancement and poverty reduction. Research that develops crop production techniques that allow the substitution of labor, management, or biological inputs for chemical pesticides, inorganic fertilizer, and fossil fuel and promotes the development or preservation of types of agriculture that preserve biodiversity To reach the poor it could invest in AKST activities that focus on (i) commodities that poor people produce and consume; (ii) regions where poor people live and (iii) the development of technology that uses the resources of the poor such as labor in labor-surplus economies.

End notes

1. Public includes government, higher education, and nonprofit.
2. Unless otherwise stated, all data on research expenditures are reported in 2000 prices and in international dollars.
3. Annual growth rates are calculated using the least-squares regression method, which takes into account all observations in a period. This results in growth rates that reflect general trends

that are not disproportionately influenced by exceptional values, especially at the end point of the period.

4 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.

5. Examples are cotton in Zambia and Madagascar and sugar cane in Sudan and Uganda.

6. 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 intensity ratios calculated in this sub-chapter.

7. Griliches (1957) was one of the first economists to analyze determinants of private agricultural R&D investments.

8. Economic surplus approach to estimate ROR can handle the distribution of benefits between the producers and consumers, but not between the different income groups.

9. 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.

10. See Bozeman (2003) for a theoretical approach to intensive analysis of the complex interactions that may determine the outcomes of scientific research.

11. Aggregate application rates for insecticide applied to cotton were not presented, although individual studies found a decrease in insecticide use associated with the planting of Bt cotton.

12. Developing world institutes involved in EVM include Mexico's Universidad Nacional Autónoma de Chiapas, Ethiopia's Addis Ababa University, the School of Veterinary Medicine of the University of the West Indies, and Rwanda's University Centre for Research on Traditional Pharmacology and Medicine. The Heifer Project International works in Cameroon with herders and healers experienced in EVM. The League for Pastoral People has worked with camel pastoralists in Rajasthan, India and has produced a field manual on camel diseases. Recent research on EVM in the developed world has come from Italy (Pieroni, 2004), British Columbia, Canada (Lans et al., 2006) and the Netherlands (van Asseldonk and Beijer, 2005).

13 See Bateman et al. (2006) for an example of the application of various measures to the non-market benefits of water quality policy in the European Union.

14. These measurement difficulties may be one reason why studies of returns to health R&D are considerably less common than studies of returns to agricultural R&D, even though health research investments worldwide are very large components of scientific research.

15. For examples of studies that consider the joint economic evaluation of policy, technology, and other factors that influence environmental quality see Abler and Shortle (1991, 1995).
16. 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.
17. For a discussion of the issues related to these estimate see Alston (2002) and Pardey et.al. (2002).
18. Moyo et al. (forthcoming) provide a recent example of the incorporation of distributional measures into economic surplus analysis of the benefits of agricultural research.
19. The MA identifies the following as the key components of human well-being:the necessary material minimum, freedom and choice, health and bodily well-being, good social relations, personal security and conditions for physical, social, psychological and spiritual fulfillment [**add citation].**

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

21 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).

22 Public sector research has produced success not only in crops such as wheat and paddy as evident from the green revolution in India, but also in maize in Africa. The maize national agricultural research systems in Zimbabwe and Kenya launched the first major breeding programs in Africa in the 1930s and 1950s respectively (Smale and Jayne, 2003). After decades of careful research both countries released breakthroughs in hybrid maize during the 1960 (Gerhart, 1975; Eicher, 1995).

23. For analysis of these reforms in USA see Huffman and Johnson (2001).

24 On the other hand some countries (example, Thailand) seems to have government policies favorable to private sector research.

25 Dasgupta and Stiglitz (1980) analyze how the poorly developed market infrastructure can influence the distribution of gains from agricultural research.

26 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. Voon (1994) and Sexton and Sexton (1996) have seen that 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.

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