NAE Chapter 2D

Changes in the Organization and Institutions of AKST and their Consequences for the IAASTD Goals

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Key Messages

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1. **During the last 60 years, NAE AKST made a major contribution to achieving food security in most parts of NAE.** Higher levels of food security were achieved in western regions of NAE compared to the eastern regions partly due to a more decentralized approach to decision-making in AKST and more integration among research, education and extension.

2. **Application of AKST in NAE has been associated with positive but also major negative socio-economic and environmental externalities, not just within but beyond the NAE borders**. These externalities are increasingly being recognized and attempts are being made to address them.

3. **Integrated AKST approaches are increasingly considered to be eligible and have been applied to varying degrees by different countries in NAE.** Many negative externalities of AKST would likely have been less significant in the past had integrated approaches (including different disciplines and stakeholders) been used earlier. Organizational integration within AKST has been scarce but as proceeded between AKST and KST at governmental level.

4. **The influence of the private sector in AKST has increased in NAE**. Thus the focus of NAE AKST shifted more towards market-driven goals and away from public goods.

5. **Competition and short-term contracts were increasingly built into the public sector funding system for AKST in NAE.** The aim of this change was to ensure quality, transparency and efficiency. However, there is some evidence that this development reduces rather than increases efficiency. In addition, short-term approaches are not necessarily appropriate for all areas of AKST relevant to the development goals (e.g. integrated approaches, research aimed at sustainability and ecosystem management)

6. **NAE AKST has played a major role in the development of the world's agro-food systems.**

    a. The international contribution of NAE AKST was established in some regions with great success but the technology transfer approach had severe consequences for the goals in some other regions. Factors that increasingly limit technology transfer from NAE to developing countries include regulatory policies like IPR, biosafety protocols and trading regimes and the fact that technologies developed in NAE are increasingly less appropriate for poor farming communities.

    b. Indirect effects of NAE agriculture, diet and food system on other areas of the world (foodprint) have increased.

7. **The main drivers of changes in AKST were shifts in paradigms, policies, regulation, science, technology and demand.** For example, in North America and Western Europe policies

and regulations have moved from a sole focus on ensuring food supply to a more multifunctional view of agriculture. Other examples are the development of intellectual property rights and the increase in organic farming.

2D.1 Organization and institutions of Agricultural Knowledge, Science and Technology (AKST)

Much of the extraordinary increase in agricultural productivity in comparison with other industries during the last fifty to sixty years was achieved by rapid technological change. Agricultural knowledge, science and technology (AKST) was a major direct driver of this change (Evenson, 1983). These advances helped greatly to overcome the food insecurity in Europe following the Second World War.

Four decades ago, global goals were expressed in terms of “in ten years, no one child shall go to bed hungry” or “increasing the pile of rice on the plates of the food-short consumers” (Falcon and Naylor, 2005). World cereal production has indeed almost doubled since 1970 based on essentially the same cropping area as of 40 years ago (Falcon and Naylor, 2005) (Chapter 2A). Despite this increase in cereal production, 5 million children die from hunger-related causes per year and there are still 850 million people worldwide suffering from undernutrition today. Even if there as been a considerable decline in the proportion of people undernourished in the developing world, there is still no big difference in the absolute numbers of the undernourished since 1979 (Table 2d, 1). Productivity of labour and land in NAE has increased partly at the expense of limited resources from other regions. The carrying capacity of some ecosystems was seriously exploited and rural livelihoods in some regions injured. NAE AKST had a key role in this development and needs to learn from its successes and failures.

The first sub-chapter of this chapter describes how the organization, institutions and processes of AKST changed in NAE since the Second World War. It starts with the historical trends in the organization of science in general and the changes in approaches and paradigms of AKST in the context of the development of agri-food systems. Then follows a description of how integration of AKST has changed over time, how AKST structures (as well as their agendas and funding) and public control of agri-food systems have developed. We attempt to assess the drivers and consequences. In the second sub-chapter we discuss what the consequences of these changes in AKST in NAE have been for reducing hunger and poverty, improving rural livelihoods, equity, and sustainable development. The final sub-chapter describes the lessons learned.

[Insert Table 2D, 1: Prevalence of undernourishment in developing countries 1979-2002 (Falcon and Naylor, 2005)]

2D.1.1 Historical trends in the organization of scientific knowledge generation

AKST is not formed or conducted in isolation from the rest of science. There is a long history of agricultural scientists drawing on and adapting findings from the basic biological, chemical and other sciences (Pardey and Beintema, 2001). Moreover, contemporary findings (especially in genetics and information sciences) serve to blur the boundaries between AKST and other sciences (CGIAR Science Council, 2005a). The societal context and trends in research and development (R&D) often apply and interact across disciplinary boundaries. Therefore, the development in organizations and institutions related to AKST should be seen in the context of trends in the organization of scientific knowledge overall.

The contemporary organization of scientific knowledge production has its origin in the education-centred scientific academies of the 17th and 18th centuries and in the invention of the research university in Prussia in the early 19th century (Rhodes, 2001). European universities had close connections to the state as codifiers of national identity, while American universities had a more pragmatic orientation towards civil society, particularly those established as land-grant universities under the 1862 Morrill Act (Celany, 2001). By 1950 the public agricultural research system of the US had developed from very small beginnings into the world's largest system, a feat made possible by the expansion of public funding for research and by the decentralized state-funded land-grant system (Buttel, 2005). The disciplinary organization of education and research emerged during the latter part of the 19th century and early 20th century through a reorganization of universities and establishment of national and international scientific societies and journals. Academic development before Second World War was characterized by growth, specialization and fragmentation.

After the Second World War, spending on higher education and research increased dramatically in the industrial countries. In the 1960s many new universities were established. Science policy was based on the so-called linear model, which assumed that investments in basic science would lead automatically to technological innovations (Stokes, 1997).

In the early 1970s awareness of environmental pollution and a range of societal problems surfaced (Klein, 1996) and the disciplinary structure of science was criticized as not adequate for solving real world problems. Concerns were already expressed in those years that the fragmentation of scientific knowledge had a negative impact on the capacity of people and societies to act in a coherent way (Apostel et al. 1972).

Up to the mid 1970s, corporate research was characterized by a relatively high degree of self-sufficiency and secrecy. Increased globalization has since led to a streamlining of industrial R&D, with a stronger emphasis on getting products to market for short-term financial returns. At the same time, corporate research started to be geared more towards interactions with R&D and business outside the mother company. Partnerships, licensing, and internal venture activities became increasingly important (Chesbrough, 2003).

The growing importance of R&D for commercial opportunity also affected the universities. With the growth in the venture capital sector in the 1970s university science could be commercialized directly, without the need to transfer a new technology first to a company. Research became a business opportunity for the researchers. Universities were encouraged to make use of this development through legislation that made it possible to assert intellectual property rights for the output of their researchers (Slaughter and

Leslie, 1997; Buttel, 2005). International organizations, such as the OECD and the EU, set up projects in collaboration with national authorities and researchers, to develop a new approach to policy in the fields of science and technology (Miettinen, 2002). The establishment of university-industry networks and the commercialization of university research was promoted by governments in a number of countries in NAE and university research was increasingly seen as an important contributor to regional and national economic competitiveness (Cooke and Morgan, 1998). The focus had shifted from basic research to a stronger emphasis on research that can be commercialized (Schienstock, 2004). This change has been criticized for having led to inequity in voice of different beneficiaries and less development of public goods.

Another aspect in the recent history of the organization of scientific research is the emphasis on value creation and accountability. Since the 1960s, the growth of public research funding in Western Europe and the US has been largely in form of competitive grants rather than budget funding for universities or research institutes. The overall share of external grants has increased. Although funding systems vary from country to country within NAE, there has been a general trend to include peer review as part of the funding decision. The aim of peer review for the assessment of grant applications is to allocate the limited funds to the best projects and that investments produce scientific value. A further development arose in the 1990s as the funding of universities, research institutes, departments, groups and individual employees became increasingly based on performance according to quantitative measures such as the number of articles in journals with a high citation index, the number of citations of one's work, the number of degrees awarded and so on. Managerial systems were also introduced, in some countries, to monitor the activities of individual scientists and to create incentives for scholarly activity. The British Research Assessment Exercise is a well-known and much-debated example[1].

The gender imbalance in science has also received increasing attention since the 1970s. Although considerable progress has been made, women are still underrepresented (Text box 2D, 1)

The organization of scientific knowledge production has thus undergone constant change. The sites of knowledge generation have become more diverse, with an increasing role for civil society organizations as they have become more professional, with increasing capacities for knowledge generation and policy input. In addition, the emphasis on the application context of research has increased (Gibbons et al., 1994). The problem-oriented nature of research has led to a crossing of disciplinary boundaries in academia (in industry they were never respected) and multi- and interdisciplinary research is becoming increasingly common (Klein, 1996). Research is also increasingly collective in nature. The number of co-publications has increased in virtually all fields and in some areas experiments can involve tens or even

[1] http://www.rae.ac.uk/

hundreds of researchers (Galison and Hevly, 1992). For most industries, science provides an important stock of knowledge and basis for innovations (Klevorick et al., 1995). In turn public science depends on industry for its instrumentation and research materials.

The increasing importance of knowledge, innovation and technology development for the economy together with decades of globalization have made the world economy more dynamic. Countries in NAE today spend up to 4% of their GDP on research and development (Figure 2D, 1). Diffusion of knowledge relevant to innovations throughout the economy is extremely important and here the traditional linear innovation model has shown weaknesses (Stokes, 1997). Systemic or interactive models were found to demonstrate the reality of innovation better while the third generation of an innovation policy is seen as a process (OECD, 2005a, b and c). This horizontal process requires governments and institutions to be more flexible and integrate policies among ministries and across other institutional boundaries to improve coherence. Despite the challenges associated with expanding knowledge and science policy into a broader innovation policy, there seems to be both a need and an opportunity for such a change, especially in the context of sustainable development. Policy integration requires interactive policy formulation and implementation. Key barriers are lack of recognition of innovation policy as a key driver of sustainable development, separate ‘missions’ and lack of understanding of related policies between different ministries (OECD, 2005c). Countries in NAE have faced different obstacles in this context and have proceeded on this path to different degrees.

[Insert Figure 2D, 1: Gross domestic expenditure of NAE countries on research and development as percentage of GDP (2004 or latest available year)]

[Insert Text box 2D, 1: Women in science in NAE including Table 2D, 2: Percentage of female professors in university faculties (different ranks, all disciplines)]

[Insert Figure 2D, 2: Proportion of women on scientific boards in EU countries in 2004 (Source: European Commission, 2006)]

2D.1.2 General trends of paradigms in societal context

2D.1.2.1 Paradigms in NAE AKST during the first half of the period

During the past century, agriculture in NAE faced two persistent challenges linked with industrialization: technological development and rising real wage rates in the non-farm sector. The agricultural sector has undergone a major economic and social change (see Chapters 2A and 2B) as it has adjusted to these forces and become more integrated into the national and world economies. The wages available in non-farm employment represent an opportunity cost to farm labor when the two labor markets are integrated. Before 1933 farm input markets were poorly integrated with non-farm input markets but by the 1970s they had become well integrated (Huffman, 1996). In the US, real manufacturing wage rates rose by a factor of 5 from 1890 to 1990; real compensation rose faster, by a factor of 7.6. These large increases represent a powerful force for drawing labor away from agriculture, made on the other hand possible by (but also causing), labor-saving technical change in agriculture (for opposing views see Hayami and Ruttan, 1971; Busch et al.,1984; Olmstead and Rhodes, 1994; Huffman, 1998a; Huffman and Evenson, 2001) . Within agriculture specialization of tasks increased through industrialization. The 1920s saw expansion of the ammonia industry for fertilizers, development of the crop hybridization technique on a commercial scale (Buhler et al., 2002) and mechanization continued.

With the number of farms declining and aggregate output growing, average output per farm grew rapidly. The average farm size in the US was 8.8 times larger in 1990 than in 1940. Productivity gains in agriculture made a dramatic reallocation of the US labor force possible. Policies that led to a decline in real food prices greatly aided the growth of cities and allowed the rising living standards for the US population. In Western Europe, the development was largely similar to that in the US. In the former Soviet Union, agriculture started to be modernized only after the Second World War and as part of a planned economy. Some small-scale subsistence farming continued to exist. In some of the former Soviet satellite states, e.g. Poland, farms remained privately owned but they were not modernized to the same extent as farms in the US or Western Europe.

The main drivers for the development of AKST in NAE after the Second World War have been technology development based on industrialization, globalization, policies and demand. The main direct driver of AKST during the early part of the period after the Second World War was a policy directed towards food sufficiency in NAE, to address the situation of food insecurity especially in Europe. This period was characterized by spectacular production gains (de Wit, 1986), through: (i) rapid integration of mechanization into farming activities, (ii) increased use of inputs, e.g. fertilizers and other agro-chemicals, adoption of hybrid seeds and crop varieties that could utilize these inputs and (iii) increased levels of publicly funded R&D, particularly in plant and animal genetics, and farm management. The discovery of the role and structure of DNA led to advances in genetics and the development of molecular biology. Legislation on intellectual property protection applied to living organisms was developed. Together these developments fundamentally changed the nature of agricultural sciences, public and private roles as well as the roles of locally provided and internationally traded agricultural goods and services (Alston et al., 1998).

Jorgenson and Gollop (1992) showed that the average annual total factor productivity (TFP)[12)] growth in the agricultural sector over the 1947-1985 period exceeded the corresponding rate for the US private

[2] Productivity analysis is an economists' attempt to approximate the "ultimate" impact of technical change on useful output without trying to identify "intermediate" successful technologies or count innovations. To accomplish this total factor productivity (TFP) expresses aggregate output per unit of aggregate input -rather than per unit of one input, say labor or land. The growth of aggregate output that cannot be explained by aggregate input - under the control of producers - is defined as TFP (Griliches, 1979; Jorgenson et al., 1987).

non-farm economy by more than 3.5 times and was more than double the rate of TFP growth for the manufacturing sector. For agriculture, productivity growth accounted for 82 % of the growth of output, while for the rest of economy, productivity accounted for only 13 % of the growth. Although there are some problems with correctly identifying causal relationships (Griliches, 1979), the evidence above and adopted from cross-sectional and over-time variation of TFP in agriculture (Evenson, 1983) indicates that investments in public and private agricultural research, public agricultural extension and farmers' schools are a major part of the explanation for the growth in productivity. Busch et al. (1984) and Huffman and Evenson (2001) reported that public research and education have been at least as important as private R&D and market forces for change in livestock specialization, farm size, and farmers' off-farm work participation. The strength of the relationship between public research and farm growth increased from about the early 1970s to the early 1980s. Private R&D and market forces have been relatively more important than public research and education for changing crop specialization. Changes in farm commodity programs had little relationship to farm structure over the study period. As profitability is influenced by local geoclimatic as well as economic conditions, good adoption decisions depend to a large extent on appropriate training (see Huffman, 1998b, for a summary of the evidence), which increases the profits of early adopters (Office of Technology Assessments, 1992; Huffman and Evenson, 1993).

Following the restoration of the food supply after the Second World War, government concern in North America and Western Europe shifted towards supporting farmers' standards of living. Technological innovation remained important, as the new technologies generally used less labor to produce a given quantity of output at any given relative input price. However, the social welfare of rural communities and income parity for primary producers became dominant drivers of change in agricultural policies, with stabilization of prices being used as the main tool (James, 1971). The Common Agricultural Policy (CAP), as formulated in the Treaty of Rome (1958), aimed to (i) guarantee food supplies at stable and reasonable prices, (ii) ensure a fair standard of living for farmers, and (iii) improve agricultural productivity through technical progress and rational production systems that would employ labor more efficiently. After 1975, sections of the farming population increasingly protested against the forces of globalization and the reform of international trade under the General Agreement on Tariffs and Trade (GATT) (Van Keulen, 2007). It has been suggested that, in practice, GATT was relatively ineffective with respect to international trade in agricultural products because of significant exemptions for agriculture, the substantial waivers that were granted, breaches of rules that were accepted as well as the ways important questions such as subsidies and state trading were dealt with (Harris, 1982).

2D.1.2.2 Impacts of paradigms in NAE AKST on low-income countries

In many developing countries, the basis for the agricultural development after the Second World War was built during colonialism, when the focus of agricultural research and extension was not on staple foods but on cash crops (such as sugar cane, tea, coffee, tobacco, spices, oil palm, cotton and rubber) (Masefield, 1972). Following independence (e.g. in Africa in the late 1950s and 1960s), the structures and methods left behind formed the basis of the R&D system of the new governments. The emphasis, especially in Africa, remained on cash crops (Roy, 1990). Although more attention was then paid to food-crop research in the subsistence livelihood context, there was little interaction with resource-poor farmers (Buhler et al., 2002).

The NAE strategy to ensure food sufficiency was reflected in the development of the Green Revolution for developing countries based on maize breeding studies in the late 1940s in Mexico. It was institutionalized in the 1960s with the establishment of the international and tropical research centers and with their union, the Consultative Group on International Agricultural Research (CGIAR), in the 1970s (for further information see subchapter 2D.1.4.1). While some of the research centers were commodity-oriented, since the 1970s most have concentrated on farming systems and often promoted input intensive farming schemes (Van Keulen, 2007). The strategy was to concentrate inputs and services on a few major crops (like wheat, rice, and corn) on the best arable lands and for the better-off farmers, to reduce food scarcity and to establish markets for farm inputs. IRRI's first major activity after its establishment was to breed rice lines that would respond to higher doses of fertilizers and be less photosensitive thus producing higher yields. Varieties which doubled and tripled yields were introduced and became dominant within a few years in several Southeast Asian countries. Overall the Green Revolution is credited with saving over a billion people from starvation (Chapter 2C).

The approach applied for the Green Revolution, although producing impressive yields did not come without severe negative impacts and after the initial enthusiasm, a whole catalogue of criticisms emerged from the late 1960s onward. Initially, social concerns took centre stage while environmental aspects came to the fore later. Practices introduced were often not appropriate or accessible for very small-scale farmers. The lack of R&D in the staple crops of the most food insecure was another issue. The reliance on external inputs led to indebtedness of farmers. The irrigation schemes requiring big dams led to flooding of previously settled areas and fertile farmland. Growing crops for subsistence gave increasingly way to the production of more cash crops. The use of chemical inputs was not optimized. The susceptibility of the new varieties to pests increased the use of pesticides which polluted of the environment. Mixed crops were replaced with monocultures of single varieties and landraces of crops were lost. Soil degradation due to agricultural intensification increased. So did dependence on external, non-renewable energy sources. Many felt that the Green Revolution led to a situation where farmers disregarded other means of yield improvement (Van Keulen, 2007; Falcon and Naylor, 2005). The "anti-Green Revolution movement" has evolved considerably since the late 1960s. It has remained vibrant to this day, and has contributed to the need for CGIAR to remain on the defensive constantly, despite its successes (Buttel, 2005).

Subsequently approaches that emphasized the multidimensional effects of technologies and which aimed to reduce negative social and/or environmental consequences while increasing positive impacts became more common in the 1970s and 1980s (Mann, 1997). Examples of such approaches are farming systems research (FSR), participatory research, Integrated Pest Management (IPM), sustainable agriculture, on-farm conservation and integrated rural development (see also subchapter 2D.1.3.1). Examples of farmer-orientated approaches include ‘farmer-back-to-farmer’, ‘farmer participatory research’ and ‘farmer-first’ (Stephens and Hess, 1999). Programs that compared the high external input approaches with traditional practices as well as with novel systems using fewer inputs started to gain ground in the 1990s.

FSR aims to provide an understanding of traditional farming expertise in relation to household goals and constraints and to describe the effects of the external environment on farmers as the focal point of the system (Stephen and Hess, 1999) (see also subchapter 2D.1.3.1). The FSR approach rapidly became popular and was strongly supported by many donor agencies (Brown et al., 1988). . FSR aims to provide an understanding of traditional farming expertise in relation to household goals and constraints and to describe the effects of the external environment on farmers as the focal point of the system (Stephen and Hess, 1999). As the limitations of the FSR approach became more apparent, the agroecosystem analysis (AEA) approach was promoted, which broadened the perspective from a primary focus on increasing farm family productivity to taking into account the long term health of the wider ecosystem (Conway, 1986; Stephens and Hess, 1999). Programs that compared high external input approaches with traditional practices as well as with novel systems using fewer inputs started to gain ground in the 1990s.The new approach of the Doubly Green Revolution (introduced by Conway in 1997) aims at sustainable use of resources and/or adaptive management in agriculture (Pretty, 1995; Conway, 1997; von Braun, 2000; Ashley and Maxwell, 2001).

Although there have been some outstanding developments in practical application of IPM in many developed countries where the ultimate goal is to decrease over-reliance on conventional insecticides, evidence suggests that in many developing countries, where the goal is an ecologically sound mix of non-chemical and chemical methods, there remains a need for much more appropriate research and implementation, especially for small farms (Way and van Emden, 2000).

Falcon and Naylor (2005) warned against transferring conservation approaches developed for wealthy countries directly to poorer nations and against underestimating the importance of productivity gains. They expressed doubts that the meaning of “sustainable agriculture” is the same in countries were a large part of the population is below the poverty line than it is in the US or in Europe (see 2D.1.2.3).

In recent decades, accelerated by the end of the Cold War, agricultural trade has been increasingly liberalized. Developing countries, in which the agricultural sector occupied a large share of the economy and employment, sought to switch from self-sufficient agriculture to commercial agriculture. One side effect of this strategy was an increase in the number of poor people and in the gap between rich and poor, as small farmers started contract production under large farm owners or lost their land, turning into tenant farmers or farm laborers. In the face of reduced development aid, programs and policies were outlined for poverty reduction, and remedies for poor areas to decline the regional disparities (Van Keulen, 2007). Developing countries have also responded to the increase in demand for food produced without chemical inputs and have been exporting organic produce to serve NAE markets, a development of interest to poor and remote farmers.

Global insecurity, civil conflicts and lack of democracy have continued to be major problems causing food insecurity (Falcon and Naylor, 2005). During the 1990's, 1 million lives were lost annually in civil wars. The combined number of annual hunger-related deaths was 8 million people, of which 60% occurred in Africa and 25% in Asia (UN, 2004; Hunger Project, 2005). Global food supply problems for several major commodities were largely solved, but the problem of access to food was not conquered (Falcon and Naylor, 2005).

2D.1.2.3 Paradigms in NAE AKST in recent decades

Negative side effects of an AKST approach focused solely on increasing the food sufficiency and farm productivity became gradually more apparent and raised concern about the externalities of agricultural technologies, in particular in terms of environment and health (e.g. effects of DDT and eutrophication). The energy crisis in the 1970s, publication of the Global 2000 report (Barney, 1981) and the Chernobyl accident in the 1980s raised concern about resource limitations. These various concerns gave rise to the concept of sustainable development, a concept brought to the fore by the Brundtland report (WCED, 1987). Declines in biodiversity and climate change also received increasing attention. The biodiversity issue in particular raised discussions in Europe about the multifunctionality and sustainability of agriculture, emphasizing the role of diverse cultural landscapes and the role of biodiversity in maintaining ecosystem functions. It led to the adoption of an ecosystem approach in World Summit on Sustainable Development in 2002 for conserving biodiversity (Plan of Implementation, 44e) (UN, 2002).

One example of an ecosystem approach is organic farming; a concept which has its roots in the late 1800's and was further developed during the first half of the 1900's. By the mid 1980s organic farming was an established alternative to conventional farming and during the 1990s its share of field area increased considerably in NAE. In Europe the area under organic farming increased from <0.1 million hectares in 1985 to 6.4 million hectares in 2004, representing 2.9% of the European field area (and 3.7% of that in the EU) (Anon., 2004). Another example is Integrated Farming Systems (IFS) (also known as

Integrated Crop Management). The objectives of IFS approach are a holistic pattern of land use which integrates natural regulation processes into farming activities to achieve maximum replace of off-farm inputs and to sustain farm income (see El Titi, 1992, and Morris & Winter, 1999, for an outline of IFS principles, origins and implementation). IFS approach has been described as a "middle course between extreme constraints of organic farming standards and the increasingly unacceptable pursuit of intensive cereal monocultures" (Wibberley, 1995). Research on various aspects relating to IFS has been taking place in NAE since the late 1970s in response to the environmental side effects of intensive farming practices (Morris and Winter, 1999). Guidelines for IFS have been developed by International Organization for Biological Control (IOBC, 1999) and IFS is promoted by organizations such as e.g. LEAF[3] in the UK and FNL[4] in Germany.

In recent years more emphasis has again been placed on increasing the voice of farmers and rural populations in the development of soil management and water management plans (e.g. Romig et al. 1996; Timmer et al., 2007). The danger of seeing farmers merely as passive recipients rather than active participants has been highlighted (Winter, 1997). Recent evidence suggests that policy knowledge cultures are able to give voice to farmers' ways of knowing nature (Morris, 2006). Farmers have also acquired new skills and knowledge on a wide range of issues related to more environmentally friendly farm management, although this process has to continue to achieve sustainable farming (Winter et al., 1997).

The many inherent conflicts that occur between environmental, economic and social costs and benefits of agriculture (ACRE, 2006) were increasingly better understood. In the 1990s food systems approaches emerged, particularly within NAE, that aimed not only to take into account environmental, economic and social aspects but also covered the whole food chain, from inputs to waste management to support systems related to food, including institutions (such as values and norms) (see e.g. Dahlberg, 1993; Tansey and Worsley, 1995). The question where the line should be drawn, when agricultural/environmental trade-offs are necessary, remains controversial (Falcon and Naylor, 2005).

The concern for rural communities and their vitality received increasing attention, which was reflected in EU policy schemes and attempts to integrate agricultural and rural policy. Abandonment of farm land, e.g. in the Mediterranean region, not only had negative social and economic consequences but often also undesirable effects on a range of environmental parameters (MacDonald et al., 2000; Suarez-Seone et al. 2002), illustrating again the multifunctionality of agriculture.

[3] Linking Environment And Farming (http://www.leafuk.org/leaf/)
[4] Fördergemeinschaft Nachhaltige Landwirtschaft e.V. (http://www.fnl.de)

Farm animal welfare became a concern in Western Europe and North America as animal production intensified and the population became more affluent and less in touch with farming. Voices questioning whether welfare concerns are compatible with animal husbandry or meat eating increased and in the 1990s radicalism proliferated within the animal welfare movement (Buller and Morris, 2003). The farm animal welfare debate has gradually penetrated farm policy within the EU and is becoming increasingly institutionalized as a result of EU and national legislation (Buller and Morris, 2003). In parallel renewed academic interest developed in human-animal relations, fuelled by a re-examination of society-nature relationships (Buller and Morris, 2003).

The central role of AKST as a driver of industrialization and structural change, especially but not solely of agriculture, has raised debate about whether even publicly funded agricultural research is equally accessible to all users and whether it is targeted to the full range of user and citizens' groups (BANR, 2002). Figures 2D, 3 and 2D, 4 show the paradigmatic changes in rural development ideas during the period of 1950 - 2000.

Over the past thirty years the agricultural component of developmental economics has declined in academia in parts of NAE, such as the US, rather than increased in response to continuing food security problems (Falcon and Naylor, 2006). Major US private universities that historically have trained large numbers of agricultural policy analysts have closed key academic units. The Land-Grant universities tended to focus on state agricultural interests rather than international agricultural R&D. Also, several states have made funding foreign graduate students more difficult (Falcon and Naylor, 2005)

In addition to the environmental concerns and the development of the concept of multifunctional agriculture, market-based economic liberalization and globalization were dominant drivers from 1986 until the early 2000s. These market forces contributed to large-scale agricultural industrialization. According to Van Keulen (2006), the main consequences were a shift from producing commodities to manufacturing products, emphasis on the entire food chain with increasing specialization, re-alignment and increasing power of retail, and flexible system adjustment to changes in consumer demand, economic conditions and technological improvements.

In addition, information technology was increasingly utilized to enhance the value chain's competitive ability. Development of new products was aided through new technologies: improved logistics brought about by integration of transport and storage systems, improved preservation systems, the communication 'revolution' (through electronic data exchange as well as investments on efficient consumer response), biotechnology, active packaging, precision farming and an increased use of integrated pest management (Van Keulen, 2006). These trends in AKST approaches after the Second World War were more prominent in research, extension and training than in higher education. In higher education the general trends were similar but changes proceeded more slowly and met with more resistance.

[Insert Text box 2D, 2: An introduction to the evolution of the concepts of ecosystem services and the ecosystem approach]

[Insert Figure 2D, 3: Paradigmatic changes in rural development thinking between the 1960s and the 1990s according to Ashley and Maxwell (2001)]

[Insert Figure 2D, 4: Paradigms in rural development 1950 to 2000 (SL=sustainable livelihoods, PRSP=participatory rural social protection) according to Ellis and Biggs (2001)]

2D.1.3 Changes in the integration of perspectives within AKST

2D.1.3.1 Evolution

In the past AKST was well integrated, if informally, with practical agriculture and beneficiaries as well as among the emerging disciplines. This changed to a strong distancing both in relation to the practitioners and among emerging disciplines (i.e. vertical and horizontal disintegration) at the time when the disciplinary basis of universities and research institutes was established. More recently AKST has moved towards re-integration. The integration of the early days was biased towards (a) farmers and rural populations at the cost of consumers and other interest groups, and (b) soil, crop and animal sciences as well as farm economics at the cost of human nutrition, ecological and social sciences. The re-integration has mainly proceeded in the form of specific integrative research approaches, often first adopted in developing countries, simultaneously with still continuing disciplinary fragmentation. Thus, in most places integration has been a functional rather than a structural, organizational phenomenon. In Europe, the strongest formal incentive to integration has been provided by recent EU Framework Programs, conceived to respond to the major socio-economic challenges facing Europe (Buhler et al., 2002).

Until to the middle of the 19th century, training of agricultural scientists did not advance rapidly. Advancement required the introduction of a new science system for agriculture, which occurred largely between 1860 and 1920. To establish this system, research methods were borrowed from the general sciences (e.g. chemistry, botany, physics) (Huffman, 1998). Even though the historical ideals of unity and synthesis of knowledge in natural sciences served as the first models for agricultural sciences, a fragmentary tendency dominated the infrastructure of science until the mid 20th century. This tendency was characterized by the splitting of disciplines into new subspecialties (Klein, 1990) and by focusing on separate topics, increasingly ignoring their interrelations. Thus agricultural science structures - both in education and research - rewarded a narrow orientation as a sign of a truly scientific approach. However, science and technology developed bi-directionally, facilitated by the agricultural roots of most agricultural scientists (Huffman, 1998). Additional methodologies were developed to meet the special circumstances associated with agriculture (Hubbart, 1998), and much applied research became multidisciplinary. In fact, Bruun et al. (2005) claim that while the earliest documented use of the term “interdisciplinary” in research appeared in general education and in the social sciences in the 1920s, the first problem-oriented interdisciplinary research was conducted in the 1940s in agriculture and defense. In many comparative studies agriculture has turned out to be one of the most interdisciplinary science fields (Clayton, 1985; Qin et al., 1997; Song, 2003). However, these studies often used the term “interdisciplinarity” meaning multidisciplinarity with no requirement of interaction of sciences. Also combinations of closely related fields turned out to be much more common than interactions between natural and social sciences (Bruun et al., 2005).

As described above and in more detail in Chapter 2C the narrow focus in AKST and agriculture on productivity of labor and land caused negative externalities which gradually become more apparent. These unintended consequences raised concern about fragmentation and overspecialization in agricultural and food sciences (Carson, 1962; White, 1967). The recognition that ecological, economic and social dimensions needed to be taken into account simultaneously led to the introduction of the concept of sustainable development (WCED, 1987; Buttel, 2005). As knowledge about agro-ecosystems has increased, past uses of environments and the potential for their sustainable management in the future has attracted particular integrative or interdisciplinary efforts (Pawson and Dovers, 2003). Interdisciplinarity is now increasingly claimed and practiced (Bruun et al., 2005).

Integration of perspectives and disciplines of different system levels, spatial and temporal scales, scientific disciplines and stakeholders in agricultural research and extension (and later also in education) has thus come into focus as a way to overcome the main barriers towards achieving sustainable development. Examples include, hard and soft systems approaches, participation, interdisciplinarity and transdisciplinarity (Table 2D, 3, Text box 2D, 3) (OECD 1972; Visser, 2001; Klein, 2004). In the mid-1960's, there was little interaction between traditional agricultural and social scientists. Although the Green Revolution (an approach relaying on natural sciences alone) was successful in reducing hunger for millions, the lack of success in using a similar approach with resource poor farmers led in the 1960s and early 1970s to the evolution of a number of new foci in international agricultural R&D (see subchapter 2D.1.2.2). Figure 2D, 5 contrasts the more traditional Transfer of Technology (TOT) approach with the Farming Systems approach. Table 2D, 3 outlines types of participation in development.

[Insert Text box 2D, 3. An introduction to systems approaches]

[Insert Figure 2D, 5 (a) Transfer of Technology (TOT) model, (b) Farming Systems Research (FSR) model (Buhler et al., 2002)]

[Insert Table 2D, 3: Types of participation in development (Buhler et al., 2002)]

For example, during the 1980s the CGIAR centers were encouraged to use multidisciplinary approaches, to increase inter-center cooperation and to collaborate with others (CGIAR, 2006), even if strong friction occurred due to structures and management (Buhler et al., 2002).

For participation of resource-poor farmers (and later other stakeholders) in R&D, several approaches with different coverage, emphasis and procedures were developed (Gonsalves, 2005). Examples already referred to include AEA, FSR and the Farmer-First approach. Others were the Rapid Rural Appraisal (RRA) (Chambers, 1983), Participatory Rural Appraisal (PRA), Participatory Poverty Assessment (PPA) (Robb, 1998), Sustainable Rural Livelihoods approach (SRL) (Carney, 1998) and Farmer Field Schools (FFSs) (Way and van Emden, 2000). The concept of participation has evolved towards governance (Ashley and Maxwell, 2001).

Food systems approaches (see subchapter 2D.1.2.3) often comprehensively involve food system actors to contribute to AKST. As interpreted by DuPuis and Goodman (2005), the US academic literature on food systems echoes alternative social norms, where “local” becomes the context in which these norms can be realized, while in the European literature dealing with alternative food networks, localism is seen as a way to maintain rural livelihoods. Irrespective of the scale, food system AKST is relevant to food policy. Food systems approaches make it possible to address and take into account societal preconditions when developing food systems and thus to contribute knowledge and tools to reduce hunger and poverty and increase sustainability.

The paradigmatic change towards sustainability, food chain approach and systems orientation created a demand for integrated, multidisciplinary educational programs and more problem- and improvement-oriented pedagogical solutions. Student-centered and experiential approaches started to emerge in higher education in food and agriculture-related subjects during the last decades. Such ideas as life-long learning, communicative learning (Leeuwis, 2004) and collective learning (societal learning) as well as participatory approaches have led to the development of innovation systems and processes within AKST. Inclusion of multiple knowledge bases, feedback loops and learning processes now aim to enable those involved to respond to emerging unpredictable circumstances. The concept is still evolving and requires more analysis of the agents involved, their behaviour, the diverse interactions that characterize it (Spielman, 2005) as well as techniques and procedures to include actors to create knowledge for use and diffusion (Hall, 2004).

Many agree that most of the constraints faced by agricultural organizations and systems around the world are institutional in nature (Byerlee and Alex, 1998) and that formal and informal institutions need to closely interact. Consequently, science for agricultural development is becoming more inclusive, consultative and participatory. It reveals new opportunities but also new challenges, such as of responding to and engaging with a widening range of interest groups, agendas, priorities and opportunities. According to the CGIAR Science Council (2005a) (in accordance with OECD (2005a, b and c)) “such a systems perspective on agricultural innovation offers the potential of realizing the promise of science and technology in the context of socio-economic development and merits increased investment in future”.

2D.1.3.2 Alternatives in integration

There are two dominant types of disciplinary integration, both appearing increasingly within agricultural sciences. The first is integration of two or more disciplinary traditions to form a new discipline involving formulation of new theoretical grounds and methodologies. Ecological economics is one example. The second type is constructive interaction among separate disciplines.

Historical evidence suggests that interdisciplinary communication and interaction often plays a key role in the emergence of new research fields, i.e. in scientific renewal and development. Thinking collectively about complex problems requires crossing boundaries both horizontally (across disciplines) and vertically (involving policy-makers, experts, practitioners, public) (Klein, 2004). This leads to participatory approaches and transdisciplinarity, and thus problem solving that crosses both disciplinary boundaries and sectors of society (Scholz and Marks, 2001). It can also involve efforts towards a new unifying theory. For example, it has been proposed that agroecology could be developed and defined as an embracing discipline for studies on the entire agro-food system in all its ecological, economic and social dimensions (e.g. Francis et al., 2003; Dalgaard et al., 2003).

Constructive interaction among disciplines does not, however, necessarily imply a genesis of a new discipline. In fact, the continuous emergence of new disciplines would merely result in the continuous reconstruction of new boundaries to be overcome.[5] The greatest value of any emergent, integrating discipline would be in establishing a common language and concepts for the participating researchers. On the other hand, interdisciplinary studies benefit from the accumulated knowledge, methodologies and traditions of the contributing disciplines. In many cases an interdisciplinary orientation would supply a broader and more flexible selection of the expertise and methods required for a sound result than would reliance on the creation of new disciplinary approaches (Heemskerk et al., 2003; Lele and Norgaard, 2005; Kahiluoto et al., 2006). The short time frame of one study and the continuously evolving research needs and objectives underline this conclusion.

Indeed, Lele and Norgaard (2005) interpret disciplines as just administrative academic artifacts, which have lost their significance as an organizing principle of science during the last quarter-of-century. For

[5] This would be the case even if the development of the new disciplines would be based on the unifying and expanding ‘rhizome model’ rather than the more commonly used hierarchical model, which involves branching into distinct, semiautonomous fields of enquiry (Bruun et al., 2005).

example, the biological sciences have dropped the historic disciplinary distinctions, e.g., between the plant and animal worlds and are organizing more according to the level of analysis from genes to organisms to ecosystems. The diversity of approaches within a discipline and the possible relatedness with an approach of another discipline leads Lele and Norgaard (2005) to suggest forgetting disciplines and thinking in terms of scientific community. A scientific community is a group of scholars who share a characteristic. The characteristic can be 1) a subject, 2) assumptions about the underlying characteristics of the factors they study, 3) assumptions about the larger world they do not study and about how what they do study relates to the larger world, 4) the models they use, 5) the methods they use and 6) the audience they strive to inform through their research. Crucial, according to them, is recognizing that organizational charts of universities do not coincide with the most important markers of difference and similarity found on different dimensions and scales. This recognition facilitates crossing boundaries between scientific communities.

Following 15 to 20 years of evolution, *participatory* techniques are also now accepted as part of the mainstream in science for agricultural development, especially in developing countries. Participation is also a way to introduce experiential and local/indigenous knowledge (Sillitoe et al., 2002) as well as knowledge about the locally adapted, traditional systems and practices to contribute to system development in interaction with science-based knowledge. Participation is an inherent part in “innovation systems”. The difference between one-directional mediation of information, according to technology transfer approaches and creation of multidirectional, interactive knowledge networks is fundamental (Figure 2D, 5) (Buhler et al., 2002). On the other hand, it has been argued that increased use of participation techniques as a research tool has not had a clear impact (Bentley 1994) and that real impact would require more than short-term technology development efforts (Humphries et al. 2000). In fact, a study in Africa claims that less than 15% of ‘experiments led by farmers’ resulted in new knowledge or technologies that did not already exist elsewhere (Sumberg and Okali 1997). The study concluded that farmers' experiments are more ‘complementary’ than ‘synergistic’ to formal agricultural research, and more closely linked to agricultural extension than to agricultural research. However, structural inclusion of the voice of the expected beneficiaries like resource-poor farmers in the organization of R&D would still be required to complement the methodological approaches.

2D.1.3.3 Barriers faced by integration

Interdisciplinarity is increasingly considered the ideal of research but it relies heavily on high-quality disciplinary research (Lockeretz and Anderson, 1993; Bruun et al., 2005; Kahiluoto et al., 2006). In applied sciences, such as agricultural and food sciences, integrative approaches have become widely accepted in education, research and extension and are increasingly demanded by funding organizations. Participation is also an approach increasingly demanded by donors of international research funding.

Although disciplinary borders have always been crossed in research, integrative approaches are difficult to handle, not yet well understood and their adoption and wide application still face major constraints (Duncker, 2001). Bruun et al. (2005) listed the following seven major barriers for interdisciplinarity: Structural barriers, knowledge barriers, cultural barriers, epistemological (i.e. relating to the theory of knowledge) barriers, methodological barriers, psychological barriers and reception barriers.

The structure of organizational decision-making and the organizational norms affect the character of research and education. The current disciplinary organization of science has been criticized as hampering interdisciplinary research and educational programs (Bruun et al., 2005), though obviously there are numerous such ongoing programs and projects. Fragmentation starts with the structure of governments, is present in the disciplinary organization of universities and research institutes, and is present in the contents of education and training programs.

An important obstacle for interdisciplinarity is also the restricted knowledge that scholars have about other fields. Funding agencies use peer review for competitive grants and it is difficult for reviewers to cover the broad content of interdisciplinary projects. High impact refereed scientific journals tend to have little interest in applied interdisciplinary research and often have a disciplinary orientation. In many countries in NAE the scientific reward system is built upon disciplinary competence assessed through success in terms of publication in refereed journals. However, interdisciplinary research has specific quality criteria, which referees with a disciplinary background are not familiar with. Mansilla and Gardner (2003) defined three main quality criteria for interdisciplinary research based on their study interviewing scientists of interdisciplinary research institutes with a high reputation: (1) Consistency with multiple separate disciplinary antecedents´ (i.e. the way in which the work stands vis-à-vis what researchers know and find tenable in the disciplines involved); (2) Balance in weaving together perspectives (i.e. the way in which the work stands together as a generative and coherent whole); and (3) Effectiveness in advancing understanding (i.e., the way in which the integration advances the goals that researchers set for their pursuits and the methods they use).

Cultural barriers include language problems (such as different technical terminology) and differences in methodologies. Problems with communication and understanding across disciplines are seen by many as the main barrier for successful multi- and interdisciplinary settings (Duncker, 2001; Bärmark and Wallen, 1980; Bauer, 1990; Porter and Rossini, 1984; Pawson and Dovers, 2003; Kahiluoto et al., 2006; Helenius et al., 2006; Mäkelä, 2006).

Epistemolgical problems occur when disciplines fundamentally interact. Reception barriers appear when issues and assumption that are dealt with are unfamiliar to the established disciplines and thus not easily accepted. Problems in paradigms, communication, organization and cognitive development are often faced in interdisciplinary research (e.g. Bärmark and Wallen, 1980). Duncker (2001) suggested that creation of “trading zones” for exchange and “interlanguages” (more or less elaborate) would be required for successful cooperation across disciplinary boarders. Many efforts failed partly because the representatives of the separate intellectual communities did not recognize the barriers created by their separate ways to understand and approach the problems (Bärmark and Wallen, 1980; Lele and Norgaard, 2005).

Institutions that have a history of interdisciplinary orientation typically can move more quickly to adopt new initiatives along these lines than those that do not (Feller, 2005). And a number of studies have indicated that the barriers for interdisciplinarity and participation can be overcome. Several solutions have been suggested, for example by the US National Academies of Science (2004). Conceptual tools to overcome the most prominent barrier in multidisciplinary studies - communicating and understanding across the disciplinary borders - have been developed (e.g. Duncker, 2001; Heemskerk et al., 2003). It is an important challenge for science education to improve proficiency in interdisciplinarity through a better understanding of the philosophy and theory of alternative approaches and methodologies in science. This can be achieved through development and adoption of appropriate procedures and tools for communicating and through practicing interdisciplinarity (Venkula, 2006).

Barriers faced by participatory approaches are largely similar to the barriers faced by interdisciplinary approaches but are often even higher for the former and more diverse as participatory approaches usually cover integration both horizontally among disciplines and vertically among different actors. For participatory approaches involving non-academics from different parts of food systems and fields of life, communication is more challenging than in integrated approaches involving solely academics. Tools to facilitate dialogues involving different values of stakeholders have been developed (e.g. Wolfe et al., 2002). Another major barrier for participatory approaches are the limited appreciation, rewards and career opportunities for researchers, a limitation which is more pronounced than in the case of interdisciplinarity (Figure 2D, 6). Eponou (1993) describes this as “the flagrant incompatibility between professional reward systems and organizational goals” adding “while the raison d’etre of most of the publicly-funded research systems is to generate relevant technologies for farmers, their employees’ reward systems do not reflect this. In some cases, researchers who devote their efforts to technology development or to establishing linkages with technology transfer may even be penalized”.

Becker (2000) listed the following barriers to adopting participatory approaches in the CGIAR centers:

1. Dominance of the technology transfer approach in the 1970s and early 1980s;
2. The view that participatory approaches are a better way to transfer technology, and should therefore be a function of National Agricultural Research Systems (NARS), extension and NGOs rather than of CGIAR centres;

3. Lack of competence and continuity in farmer-relations due to short-term contracts;
4. Continuation of a narrow focus on natural sciences in agricultural R&D in CGIAR with a relative under-investment generally in developing countries, especially in sub-Saharan Africa (Mbabu et al., 1998);
5. Low level of commitment by senior management;
6. Reward system in the CGIAR centers (and elsewhere) based on production of quality data that can be published in high impact factor refereed journals;
7. Prevailing commodity orientation that mitigates against a systems perspective.

[Insert Figure 2D, 6: Hierarchy of status as suggested by Buhler et al., 2002 (adapted from Chambers, 1997)]

A barrier of growing significance, specific for participatory approaches is the “digital divide” (i.e. the difference in access to information technology) between the developed and the developing world and between the rich and the poor. It has contributed to inequity and inefficient use of AKST.

Integrated approaches, to be feasible and to become more commonplace, require major institution-level changes in curricula, incentives, evaluation criteria and accountability. Indeed, the expectations for integrative scientific approaches and the practical preconditions offered by the performance of the knowledge, science and technology generation system often seem to be in conflict (Lele and Norgaards, 2005).

2D.1.3.4 Risks associated with integration

Although interdisciplinarity has been increasingly considered the ideal of research, increasing the level of integration has so far been a rocky path. The barriers described above are not the only challenges as there are also risks associated with increasing the extent of integration. These risks need to be minimized and managed carefully to ensure that integrative approaches help rather than hinder achievement of the goals of this assessment.

Interdisciplinary research relies heavily on high-quality disciplinary research. However, many of the changes implemented in recent years in the name of integration, rationalization and quality control have resulted in cuts in funding of disciplinary research and confusion and disillusionment of scientists involved in such research. Finding the optimal balance between integrated approaches and disciplinary approaches has been (and will continue to be) an important challenge. As structures were changed and the limited funding available for the development of new AKST stretched across more disciplines, funding available to sectors of disciplinary research that have long provided essential knowledge for AKST has gradually been reduced in some regions of NAE. This has resulted in fragmentation and loss of continuity of the science base, weaker links between science and application and less security for the future (OSI, 2006). There is currently considerable concern that the losses in disciplinary research have been already too severe in some areas. This fragmentation and loss of important expertise limits the capacity to respond adequately to current as well as future challenges facing agri-food systems and such disciplinary expertise is not quickly rebuilt. Concerns like these partly explain the lack of enthusiasm for integration amongst senior management referred to above. It has been recommended that the costs and time needed for re-building expertise be included in evaluations of area of research considered for discontinuation. The strategic planning of public sector funding organizations needs to be better joined up at a national level to help maintain crucial scientific expertise and facilities (OSI, 2006). There are also initiatives to improve strategic planning at an international level to avoid duplication of effort at a time of increasing funding constraints (EURAGRI, 2005). A more integrated approach and multi-disciplinary research programs should not lead to less disciplinary research and a depletion of agricultural research but should be seen as a reinforcement of agricultural research.

Recent decades have seen reduced public funding for extension services, which has weakened the links between science and application (Lambert et al., 2007). Yet advisors will have a crucial role to play in achieving sustainable farm practices and they will need to require new skills and cover a broader subject area than ever before (Lambert et al., 2007; Ingram and Morris, 2007). Extension activities not only need sufficient public sector funding but also need to be well coordinated. In addition there should be guidance, support and promotion of best practice to those undertaking extension activities outside the public sector (Winter et al., 2001; Lambert et al., 2007). Better mechanisms need to be established to link agri-environmental science findings to various forms of extension. The interface between research and extension should be more open and direct (Winter et al., 2001).

As described above, peer review with lacking competence in systems approaches, interdisciplinarity and participation, and their quality criteria (see 2D. 1.3.3) is seen by some as a barrier to integration. In fact the use of peer review has increased in recent years and continues to be considered throughout NAE as an essential tool to ensure the highest quality of science (Bretschart, 2005; Danford, 2006; OSI, 2006). Many would consider less use of peer review a step in the wrong direction, risking a reduction in the quality of the crucial evidence base on which policy depends.

Systems approaches may not be appropriate for all situations. For example, many pest and disease problems transcend commodity. There is also a need to understand longer-term changes, e.g. in crop production the average crop rotation exceeds the life span of most projects.

The integration of different structures carries the risk of increasing the administrative burden and wasting funds as it often leads to a new layer of bureaucracy. Approaches in integration that do not increase the layers of bureaucracy may be a challenge but appear a more efficient use of limited resources.

The development of participatory approaches and their important role has been described above. Sumberg et al. (2003) warned against seeing farmer participation in research primarily as a route to the empowerment of local populations and almost independent of any eventual research outputs, as “such an approach can only be wasteful and disappointing”.

Balancing the influence of stakeholders in the development of AKST agendas will be important to ensure that funds are focussed on the areas most relevant to society and the environment (see also subchapters 2D.1.4.3.3 and 2D.1.4.5). Despite much progress in theoretical work there is still little agreement amongst social scientists regarding the best methodologies to be used for citizen participation (Pidgeon et al. 2005). The importance of using appropriate methodology is exemplified by a major multistage deliberation exercise on the commercialization of agricultural biotechnology conducted in the UK in 2003 which, due to the use of a self-selecting sample of the population, did not result in a accurate representation of the views of the UK population (Pidgeon et al., 2005).The need to design analytic-deliberative processes that can accommodate a very wide plurality of views in public policy discourses and decisions has been recommended (Pidgeon et al, 2005).

New technologies represent particular challenges in terms of citizen participation. The problems the general public faces in understanding the potential risks and benefits associated with biotechnology are one recent example. However, the complexity of biotechnology may well pale in comparison to new inventions now in the pipeline such as nanotechnology (Grove-White et al. 2000). Research suggests that in general, people rely on the judgement of trusted others rather than making choices vis-à-vis technologically complex new products simply in a rational fashion (Grove-White et al., 2000). The news media have so far preferred to exploit and heighten public fears of certain new technologies although hope has been expressed that they can change “to encourage mature discussion of the implications of uncertainties and unknowns surrounding new technologies and their insertion into everyday life – as necessary for constructive public debate” (Grove-White et al., 2000). The same encouragement can be addressed at other organisations the general public uses as trustworthy sources of information. An important aspect is also thought to be the need to pay more attention at the earliest development stages to the social constitutions (i.e. the particular social values and assumptions individual technologies embody) new technologies are perceived to have (Grove-White et al. 2000). However, choices of citizens are also contributed to by their value systems, where scientists are no experts,

2D.1.4 Development of structures, funding and agenda of AKST

While the first parts of this sub-chapter focused on paradigms of relevance to AKST in the context of the development of agri-food systems, followed by a description of the levels of integration or disintegration of approaches, the present section describes the history of the AKST structures, their agendas and funding.

2D.1.4.1 Establishment of structures

Much of the invention and technological improvement in NAE agriculture before 1840, and to a lesser extent up to 1900, came about through the activities of private individuals such as innovative farmers, blacksmiths and estate owners. Accordingly, a large share of the technical advances from this informal system was realized in the form of mechanical innovations rather than biological advances (Evenson, 1983; Hayami and Ruttan, 1971). Agricultural societies provided early support to teaching and research institutions. Both the performance and the funding of agricultural research in the U. S. has since then been shared between private and public interests.

In most countries in NAE formalized agricultural research organizations were established from the 1840s onwards. The first experimental stations staffed with professional scientists were established in the UK, France and Germany, followed soon by most other European countries. By 1875 there were ninety national experimental stations in Europe (Grantham, 1984). In the US, Congress passed the first Morrill Act in 1862 to assist the states in establishing land-grant colleges to teach agriculture and applied sciences. Research at these and other institutions was assisted by the Hatch Act of 1887 (which established land-grant experiment stations on land-grant college campuses) and the Second Morrill Act in 1890 (Buttel, 2005). Statewide informal education of colleges was authorized and assisted by the Smith-Lever Extension Act of 1914. In contrast to the German model, the US experimental stations were established under the direction of a state land-grant college or university. In order to assure the dissemination of the knowledge produced by these investments, the Cooperative Agricultural Extension Service was created in the US as a partnership between federal, state, and county governments. In Europe higher education in agriculture was in most cases arranged as an activity of existing universities. In further contrast to the US, distribution of their results to farmers was not a major focus of the activity of the experimental research stations in Europe. Farmers' institutes, traveling agricultural-college short courses, and field demonstration activities were turn-of-the-century precursors to extension.

The second wave of public commitment to expansion of agricultural R&D in NAE took place in the first half of the 1900s, based on crucial developments in the basic and applied sciences, especially in genetics. These developments fundamentally changed the roles of private and public actors (organizations and their personnel, etc.) in science. This change coincided with the end of the Second World War, a period when science (and agricultural R&D in particular) was widely considered a potential source of major improvements in social welfare. This perception fostered a strong third wave of development of structures for agricultural R&D.

The governmental responsibility for AKST is divided in many different ways in NAE, but the responsibility is often shared among different ministries. In Russia and the now independent former Soviet states a highly centralized AKST was established. In contrast, in the US decision-making was decentralized and occurred largely at the regional level (Table 2D, 4), a situation that has fostered diversity, innovation and local adaptation (Miller et al., 2000). In countries in Western Europe, levels of decentralization vary. Germany is an example where decision making in agricultural research and education also occurs to a great extent at the regional ('Laender') level.

As outlined above, the *higher education, agricultural research and extension systems* of the US were established in a relatively integrated way. In contrast, in Russia and in the CEE countries which followed the Russian model, AKST organization have been highly divided and research, education and training were not integrated. In Russia, AKST is still divided into science academies that also provide the highest education to universities, research institutes and training systems. There was and is no public extension service and students have little practical training. The decentralization and integration of US AKST is considered an important part of the US's success in increasing productivity of agriculture (Huffman and Evenson, 1993). Huffman (1998) carried out a comparative analysis of the development in productivity of agriculture in relation to the organization of AKST, and of the development of US public education in relation to the organization of schooling research. Huffman (1998) concluded that the easy access to important advances in related sciences and scientific methods seems to be of major importance for success. In contrast, the inefficiencies in Russian agriculture were a major factor in several changes in Soviet leadership and finally the collapse of the Soviet socialism (Miller et al., 2000). In the rest of Europe, the integration of universities, agri-food research and extension varies significantly among countries. For example, the Swedish structure is similar to that in the US while in France, Denmark and Finland the higher education and strategic R&D are organizationally separated.

[Insert Table 2D, 4: A comparison of agricultural higher education in the US and Russia (Miller et al., 2000)]

International agricultural R&D (see also subchapter 2D.1.2.2) represents in comparison a relatively recent institutional innovation as it was only initiated in 1943 with the Mexican government -Rockefeller wheat research program. This initial program became a model for many subsequent international agricultural research initiations in the 1960s, including the four international agricultural centers CIAT (tropical agriculture, Colombia, established in 1967), CIMMYT (maize and wheat, Mexico, 1966), IITA (tropical agriculture, Nigeria, 1967) and IRRI (rice, Philippines, 1960). The subsequent development of the international agricultural research centers took place mostly under CGIAR, established in 1971 to mobilize science and financial support to serve the needs of the poor. CGIAR is a strategic alliance of countries, international and regional organizations as well as private foundations supporting international research centers, which work with the national agricultural research systems and civil society organizations including the private sector. CGIAR is funded mainly through the development aid funds of developed countries, either directly to the centers or through contributions to agencies such as the World Bank, the Asian Development Bank and the European Union. CGIAR established a Technical Advisory

Committee (TAC) to ensure the relevance of CGIAR-supported research and the quality of science at the centers. The expansion phase of the international AKST was in the 1970s.

In many developing countries, the National Agricultural Research Systems (NARS) started to develop based on the inherited colonial export-oriented R&D structures, which were built with the "top-down" principle. Not surprisingly the structures in the developed and developing countries were therefore closely related. It is estimated that approximately 90 % of agricultural researchers in Africa were still expatriate in the early 1960s but this proportion had declined to 20 per cent by the early 1980s (Buhler, 2002).

2D.1.4.2 Drivers of change

Following decades of government service expansion, the mid 70s to the late 80s became an era of less government. However, a new paradigm emerged for the 90s: not less government, but better government, involving a shift to more enlightened regulation, improved service delivery, devolution of responsibility, openness, transparency, accountability, partnership and "new public management" (OECD, 1999).

In many developed and developing countries, public agricultural R&D policy changed dramatically between the early 1980s and the end of the 1990s. The long period of sustained growth had ended (Subchapter 2D.1.4.3) due to general fiscal constraints and a more sceptical view of the social benefits of R&D. Clearer justification and accountability for R&D funds was requested. In Eastern Europe, the drastic changes in the socio-political system led to a re-orientation towards a market economy from about 1990, although not to the same extent in all affected countries. These changes were associated with a period of disturbance and restructuring of agri-food systems and AKST. The large budget deficits in the 1980s forced also US agricultural R&D into a contracting mode (Huffman and Just, 2000; Alston et al., 1998), while individual states largely resisted pressure to shift to peer-reviewed competitive grants (Huffman, 2005). On the other hand, new participants emerged in the private research sector in NAE following the introduction of incentives such as periodic strengthening of intellectual property rights (IPRs) (e.g. in the 1930s, 1970s, and 1980s) and the subsequent shift of the boundary between publicly- and privately-funded research (Fuglie et al., 1996). This development was intentionally fostered by governmental science policies. Governmental science policy were also modified to broaden the scope of agricultural R&D and increase its efficiency (Rubenstein et al., 2001; Huffman and Just, 2000). This has made the agricultural R&D environment increasingly competitive and proprietary.

During the last decade, many OECD countries have adopted the explicit goal to change the structure and function of their agricultural R&D organizations. They tended to bring AKST policies closer to the general public KST policies. Also, there was a shift from the unidirectional paradigm of knowledge transfer to a paradigm of interactive knowledge networks involving multiple stakeholders, which led to various forms of peer review and merit review (OECD, 1999) of research, educational and extension programmes.

Alston et al. (1998) list the following major institutional changes in public agricultural R&D during the last quarter of the last century in developed countries, based on a study on five OECD countries (US, Netherlands, UK, Australia and New Zealand):

A study (Alston et al., 1998) of public agricultural R&D during the last quarter of the 19th century in developed countries (using the five OECD countries US, Netherlands, UK, Australia and New Zealand as case studies) identified the following major institutional changes: (i) a shift towards using public funds for more basic research rather than applied or near-market research, (ii) a trend towards joined funding of near-market research using different mechanisms, (iii) strengthening of oversight and accountability mechanisms, (iv) measures to increase competition among researchers for productivity and resource allocation, (v) measures to privatize public agricultural research institutions, and (vi) increasing the cost effectiveness of public agricultural research facilities.

According to this study, the similarities between the countries are derived from a common set of “vectors for change” , which include (i) the more market-oriented “laissez-faire” role of the government in the management of the national economy, (ii) the changing nature of the scientific and agricultural research, (iii) the development of a more skeptical view of the potential benefits of agricultural R&D due to the decrease in the share of agriculture in the national economy, and (iv) the growing influence of the “non-traditional” interest groups such as agri-business, food industry, NGO’s (like environmental and consumer associations), food-safety lobbies and in the international AKST also farmer organizations (Alston et al., 1998; CGIAR Science Council, 2000).

2D.1.4.3 Development of funding and agenda in NAE in the global context

2D.1.4.3.1 Development in NAE

Between 1945 and the mid-1970s there was a period of rapid growth rates in public agricultural R&D expenditures in NAE. Many NAE countries financed large-scale expansions in their national science research-education systems, particularly in the 1950s and1960s. Alston et al. (1998) analyzed the data available for 22 OECD countries[6], which show that agricultural R&D spending in the OECD grew on average by 7 to 8 % per year during the 1950s and 60s. Alston et al. (1998) suggested that such growth rates were probably not sustainable in the long term and that by the 1970s in many OECD countries publicly funded agricultural research had become a mature industry characterized by modest rather than rapid expansion. The 1970s saw a growth rate of 2.7% per year on average for the OECD analyzed.

[6] OECD totals reported by Alston et al. (1998) included the following NAE countries: Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the UK and the US. Non-NAE countries included in their data were Australia, Japan and New Zealand.

Some NAE countries saw higher growth rates, e.g. the annual growth rate was 4.2% in the Netherlands for the period 1971-81. However, the 1980s saw a further decline in real public agricultural R&D expenditure growth rates in some regions of NAE. While the annual growth rate in the US remained relatively stable (2.3% for the period 1981-93), the growth rate in the Netherlands was only 0.9% while expenditure even declined in the UK by 0.2% over the same period. The dramatic declines in growth rate in the Netherlands and the UK were associated with relatively radical changes in the institutional organization and management of public agricultural research during the 1980s compared to other countries in NAE (Alston et al. 1998). In the 1990s public expenditures recovered somewhat but growth rates remained modest compared to the 1960s and 1970s. Despite minimal funding increases, demands on the public system grew increasingly complex due to increasing awareness of food safety issues, environmental externalities and increasing food consumption (Rubenstein und Heisey, 2005). This has led to efforts within the EU in recent years to coordinate funding for AKST to minimize duplication of research between member states. Such efforts have attracted criticism by the farming community concerned that they may reduce national competitiveness.

The share of public agricultural research funds given to universities increased considerably from the 1970s onwards in parts of NAE, particularly the US, UK and Netherlands, indicating a shift towards more basic research. Between 1971 and 1993, the university share of public agricultural R&D spending increased in the UK from 2.3 % to 14.7 %, in the Netherlands from 14.9 % to 31.9 % and in the US from 67.3 % to 74.1 %. In contrast, in the other countries analyzed by Alston et al. (1998) the average share of public agricultural R&D given to universities remained about 28% over the same period.

In the US funding for agricultural research, until the 1950s the centerpiece of civilian R&D has now declined to what has been described as “a footnote in the federal budget” (Busch, 2005). Smith-Lever funds, the main source of federal funding for extension, have been declining in scope for more than a decade and the Hatch funds, the “lynchpin of federal support for agricultural experiment stations”, are also now under attack, partly because of an increasing preference for competitive grants over formula-based funding and also because of fragmentation of the constituency for such funds (Busch, 2005). The key niche occupied by colleges of agriculture has shrunk in scope and there has been a tendency to shed specialists dealing with minor crops while maintaining competence in major crops. These crops are, however, increasingly controlled by the private sector, while minor crops are of little interest to the private sector as they lack the potential for significant profit in input supply. These and other factors contributed to weaken the once strong links between farmers and especially farm commodity groups and colleges of agriculture (Busch, 2005). For more than a century, the colleges of agriculture were at the center of the research agenda in the US. They had few competitors as private biological research was mostly unprofitable. However, Busch (2005) suggests that in the US the agricultural research agenda is today heavily influenced the private input sector and, to a lesser extent, by processing industries.

The public agricultural R&D intensity ratio (ARI; public agricultural R&D expenditure relative to the value of agricultural output) increased throughout the period 1971-1992 in most NAE countries analyzed by Alston et al. (1998). An exception was the US where the ARI barely increased. The average science and technology research intensity ratio for the countries analyzed by Alton et al. (1998) increased by a much smaller proportion than the ARIs.

Although these research intensity ratios suggest that agriculture has been treated relatively favorably in many NAE countries in terms of public R&D funds, a different picture emerges when trends in agriculture's share of total publicly performed science and technology are examined (Alston et al., 1998). In fact, the share of agricultural R&D out of the overall R&D funding declined in the 1980s to the early 1990s in the countries analyzed by Alston et al. (1998). In the Netherlands, for example, agriculture's share of the total public R&D budget declined from 14.5 % in 1981 to 12.4 % in 1993. In the US it declined from 6.2 % to 5.6 % and in the UK from 7.1 % to 6.6 % over the same time span. Across the 22 OECD countries analyzed, agriculture's share of the total public science and technology R&D budget declined on average from 8.9 % in 1981 to 7.4 % in 1993, a proportional decrease of close to 17 %. A likely cause for the changes was pressure to reallocate funds to other science R&D programs (such as health) (Alston et al., 1998). This shift was also reflected in the declining space devoted to agriculture and natural resources in major journals (e.g. economic journals) while coverage of issues such as manpower, labour, population developments, welfare programs, consumer economics as well as urban and regional economics increased (Ryan, 2002). A meta-analysis conducted by Alston et al. (2000) of all the available studies of the impact (in terms of rates of return) of agricultural R&D between 1953 and 1998 found no evidence of a decline in returns to investments throughout these decades. CGIAR Science Council (2005a) concluded that these results imply that equally large returns to current spending on agricultural R&D will also be feasible in the future. During the 1990s agricultural R&D spending in the US increased again, from 3216 million in 1991 to 3828 million in 2000 (in 2000 international dollars), representing 16.1% and 16.6% of the global total, respectively (CGIAR Science Council, 2005a). The US is also increasing funding for more basic agricultural research (Danford, 2006).

More generally in OECD, governments have in the 1990's been prepared to fund all or most higher education costs, depending on their general policy on tuition fees (OECD, 1999). However declining student numbers have increased the pressure to reduce public funding. They are prepared to fund also "basic" and "pre-competitive" sectoral research but economic sectors are increasingly encouraged to fund sector specific research. Responsibility for extension/development work has been increasingly shifted towards the clients. A number of countries have a strong commitment to fund public-good type extension, while most extension workers are nowadays involved in monitoring and implementing public regulatory schemes (OECD, 1999).There has been a recent trend for governments to fund programs rather than institutions, and an effort towards addressing competitive grants to longer-term programs or themes rather than to individual projects (OECD, 1999).

Investments of the private sector in agricultural R&D has generally increased since the early 1980s and were estimated to constitute by 2000 around 55% of all agricultural R&D in developed countries (Figure 2D, 7, Table 2D, 5) (CGIAR Science Council, 2005a). During the 1990s, according to Beintema et al. (in press), the shortcomings of the public research model led to the gradual emergence of private sector/broadly market-oriented reforms in agricultural R&D investments. This development was facilitated by the interests and the capability the private sector had developed in AKST investments (Beintema, in press). The transition was facilitated by structural adjustment policies imposed in many NAE countries, the global changes in trade regime as well as developments in biotechnologies (Beintema, in press). Not only has research directly carried out by private sector organizations increased but also the private sector funding in public sector organizations and universities (Beintema, in press). There was also a net flow of public funds to private research (Alston et al., 1998).

[Insert Figure 2D, 7: Funding for agricultural research in the US]

[Insert Table 2D, 5: Public and private agricultural R&D expenditure, circa 2000 (CGIAR Science Council, 2005a)]

Privately performed R&D has become a prominent feature of agricultural R&D in rich countries, including many countries in NAE (Alston et al. 1998; Rubenstein and Heisey, 2005). The relative importance of private agricultural R&D in total agricultural R&D varies between countries. In the UK, for example, the private sector was estimated by Alston et al. 1998 to perform over 60% of all agricultural research in the UK and more than 50% in the US and the Netherlands by the late 1990s (Alston et al. 1998). Growth of the private sector spending slowed at the end of 1990s but the balance continued to shift towards the private sector.

In most NAE countries, the private sector has had a long-standing triple role in the public agricultural R&D: firstly through involvement with the management of the publicly provided funds as the primary user, secondly through funding publicly performed research, and thirdly by performing research using public funds.

Since the Second World War, the scope of agricultural R&D in NAE broadened considerably and increasingly included issues relating to post-harvest, food chain, nutrition, rural development, environment and sustainability (Huffman and Evenson, 1993; OECD, 1999). Funding initiatives to increase integration of social and life sciences and economics have increased in NAE in recent years. Examples include the

6th framework programme of the European Commission[7] and the Rural Economy and Land Use Programme (RELU)[8] in the UK. On the other hand, it has been suggested that AKST has made only a limited contribution to national policy making, that this has often been primarily by economic research and that contributions to public debate have been sporadic (OECD, 1999).

Public research and private sector research inevitably tend to focus on different areas of R&D. For example, approximately 12% of private R&D focused on farm-level technologies compared to around 80% of public R&D in 1993 (Alston et al., 1998). Chemical research accounted for more than 40% of private agricultural research in the US and the UK and for nearly three quarters of privately funded agricultural research in Germany, while 58% of the private research in the Netherlands focused on food products. Particular areas of private agricultural R&D tend to be concentrated in particular countries. For example, Japan, the US and France account for 33, 27, and 8 %, respectively, of all food processing research carried out by the private sector in OECD countries. Chemical research related to agriculture is even more concentrated with the US, Japan and Germany representing 41, 20 and 10 % of all reported private-sector research (Alston et al., 1998). Data available for the US and the UK show a dramatic shift in private sector expenditures from farm machinery and post-harvest processing in the 1960s to agricultural chemicals, plant breeding, veterinary and pharmaceutical research by the end of the 1990s (USDA, 1995; Thirtle et al., 1997).It has been suggested that the application-orientation of the private sector to some extent fills the gap between technology generation and extension that existed in the public research model (Beintema, in press). However, there is concern that the shift towards a higher proportion of privately funded agricultural R&D moves the focus away too much from public goods, equity and distributional issues (BANR, 2002). As the private sector can retain few financial returns in the short term from innovations that improve environmental benefits and food safety, the public sector remained the primary source for new technologies with these characteristics (Rubenstein and Heisey, 2005). In recent years, as environmental, food quality and income pressures in agriculture increased, the private sector has started to take a more long-term view and fund R&D into more sustainable farming practices[9] (Morris and Winter, 1999; Walker, 2001).

There has also been an increasing involvement of the private sector in agricultural extension (Umali and Schwartz, 1994). Public extension systems have been substantially down-sized or phased out altogether in some European countries (Read et al., 1988; OSI, 2006; Beintema, in press). In North America and Western Europe, technical support to farmers is now to a large extend provided by agricultural specialists who work for private sector firms, especially input supply companies. Some Eastern European countries, such as Poland and Hungary, still have large public agricultural extension systems. Other countries in

[7] http://ec.europa.eu/research/fp6/pdf/fp6-in-brief_en.pdf
[8] http://www.relu.ac.uk/ (accessed 27 Feb 2007)
[9] http://www.voluntaryinitiative.org.uk/Content/Default.asp (accessed 27 Feb 2007)

European and the Commonwealth of Independent States are attempting to privatize their extension systems, with mixed results (Beintema, in press).

The focus of public sector extension services in parts of NAE has gradually changed from an agricultural production-centered advisory regime to an environmental regime (Winter et al., 2001). Farm visits by advisors remained the most effective of all methods of communication and the most valued by farmers (Ingram and Morris, 2007). Advisors remain an essential component of the agricultural knowledge system despite increased use of other mechanisms that increase farmers' learning, such as demonstration farms, farmer-farmer interaction and group learning. In fact, advisors have become more important as farming, markets and regulations become ever more complex. Their role is further amplified by farmers' increasing reluctance to share knowledge with their peers in order to retain a competitive advantage. However, the role played by different types of agricultural advisors in the transition to more sustainable farming systems is still only partly understood (Ingram and Morris, 2007). Extension services faced some problems serving the increasing numbers of part-time farmers (Suvedi et al., 2000).

2D.1.4.3.2 NAE in the global context

Total spending on science in the world is highly spatially concentrated. The US, Japan, Germany, France and the UK accounted in 2000 for 68% of the world's total science spending (CGIAR, 2005a). These five countries together with Italy, Canada, China, India and South Korea contribute 81.4% of the world total scientific investment. In contrast, the share of the 80 countries that spent least on science had slipped further from only 0.36% in 1995 to 0.33% in 2000. These 80 countries account for 7% of the world's population and 1.7% of the world's GDP (CGIAR, 2005a).

CGIAR (2005a) reports that over the past two decades, worldwide public investments in agricultural research have increased by 51% in inflation-adjusted terms (from an estimated $15.2 billion in 1981 to $23 billion in 2000). Figures for the 1990s reveal that for the first time developing countries as a group undertook more of the world's public agricultural research than developed countries (CGIAR, 2005a). Agricultural R&D has become increasingly concentrated in a handful of countries. In 2000 China, India, Brazil, Thailand and South Africa accounted for 53.3% of the developing world's public agricultural research in 2000, up from 40% in 1981. The US, Japan, France and Germany continue to provide two-thirds of the public research done by rich countries in 2000 with little change compared to two decades before (CGIAR, 2005a).

Spillovers of science and technology are increasingly recognized as an important feature of the history of agricultural development (CGIAR, 2005a). Alston (2002) suggests that half or more of the local productivity gains in agriculture during the past decades can be attributed to *"spill-in" technologies* developed elsewhere, even if spillovers have turned out difficult to plan for. Unfortunately, spillovers can sharpen the gap between rich and poor countries due to different facilities for utilisation. For example, Pardey et al. (1996) showed that research conducted in CIMMYT and IRRI in developing countries provided large economic benefits for the US, due to technology spillover. Also, rich countries are increasingly moving away from technologies appropriate for poor farming communities. In addition, regulatory policies like IPR, biosafety protocols, trading regimes and specific restrictions for moving genetic material are increasingly influencing the extent to which spillovers of R&D in NAE are feasible or economically viable (CGIAR Science Council, 2005a). On the other hand, new developing countries have appeared on the supply side of technology development. In particular, China, Brazil and India have expanded their basic research capacity, reducing their dependence on adaptive R&D and becoming potential sources for the poorest countries relying on adaptive research (CGIAR Science Council, 2005a).

2D.1.4.3.3 International AKST

NAE countries play a major role in funding and shaping agendas for international AKST. This subchapter can only provide a short outline of the changes in funding of international AKST in the last decades. A more detailed analysis is provided by Beintema et al. (in press) in the global section of the IAASTD.

The funding of international agricultural R&D has followed a similar pattern to the funding of national public agricultural R&D in the contributing countries, although its expansion phase occurred later. During the first development period, from 1971 to 1982, real spending of CGIAR grew by 14.3% per year and further research centers covering more commodity crops were established (Alston et al., 1998). In the second phase (mid 1980's to 2001) real spending started to stagnate and finally decline, although the scope continued to broaden to cover more commodities, farming systems and environmental R&D. Spending grew only 1.4% per year from 1985 to 1991, and only 0.7% (corresponding to a decline of 1.8% in real terms) from 1992 to 2001. Simultaneously, the share of restricted funding increased from 36 % to 57% from 1992 to 2001 (Figure 2D, 8). The budget of CGIAR budget has started to increase again in the present century with an average annual growth rate of 6.1% (CGIAR, 2005) (Figure 2D, 9).

As referred to above, CGIAR is funded mainly through the development aid funds of developed countries (many of which are based in NAE), either directly to the international research centers or through contributions to agencies such as the World Bank, the Asian Development Bank and the European Union. The total financial contributions (in US dollars) to CGIAR up to 2005 were 2517 million from European countries, 1536 million from North America, 1488 million from international and regional organizations (incl. the World Bank), 731 million from Pacific Rim countries, 199 million from foundations and 159 million from developing countries. During the current century, the top three contributors have been (depending on the year) the World Bank, US, Japan, UK and Commission of the European Community (CEC). There has also been a notable increase of 34% in the contribution from developing countries during the last reported year. CGIAR currently supports 8500 scientists and staff in 16 centers and more than 100 countries. However, in 2000 CGIAR only represented 1.5% of the 23 billion US dollars global public sector investments in agricultural R&D and 0.9% of all public and private agricultural R&D spending (CGIAR Science Council, 2005a).

[Insert Figure 2D, 8: The increase in the share of restricted funding to CGIAR (World Bank, 2003b)]

[Insert Figure 2D, 9: Nominal and real expenditures of CGIAR-supported centers (CGIAR Science Council, 2005a)]

The initial objective of international R&D was to increase the amount of food in tropical countries which faced serious scarcity. It therefore gave highest priority to research on cereals. Soon, however, the research portfolio was broadened to include not only wheat, maize and rice but also sorghum, millet, cassava, chickpea, potato, other food crops and pasture plants. Towards the end of the 1970s CGIAR branched out into several other new areas of activity such as livestock research, farming systems, conservation of genetic resources, plant nutrition, water management, policy research and services to national agricultural research centers in developing countries (Figure 2D, 10) (CGIAR, 2006). During the 1980s, the environmental, multidisciplinary and systems-oriented, as well as cooperative approaches were strengthened, yet were not mainstreamed. At the end of the decade, forestry and agro-forestry were also included and during the 1990s fishery and water management (CGIAR, 2006). In the 1990's the mission developed to emphasize sustainability and sustainable agriculture, nutrition and well-being, the interests of low-income people and food security. The productivity-enhancing agricultural research was reduced, while the expenditures on environmental protection and policy improvement increased (Figure 2D, 11, World Bank, 2003b). In the 2000's, the World Bank started to emphasize again the importance of raising agricultural productivity but stressed that a global rather than just a national or local view is crucial (World Bank, 2003b).

[Insert Figure 2D, 10: The development of the research agenda of CGIAR from 1960 to 2005 (CGIAR Science Council, 2005b)]

[Insert Figure 2D, 11: Average annual change in CGIAR's expenditures by type of research activity (adjusted for inflation) for the period 1992-2001 (World Bank, 2003b)]

In 2000, 37% of the world agricultural R&D was performed by private firms, but 94% of that in developed countries (Table 2D, 5). In many developing countries the share of the private sector in agricultural research continues to remain insignificant. Possible reasons include a linkage between national income of the countries and the role of private sector in agricultural research as well as legal and administrative problems. Given the tenuous market realities, it seems to be unrealistic to expect a rapid development of locally performed agricultural R&D in poor countries, which emphasizes the potential of linking to private AKST elsewhere through public-private joint venture arrangements (CGIAR Science Council, 2005). Mutually negative perceptions of public and private players, unresolved issues of risk and liability as well as high transaction and opportunity costs have also been suggested as barriers hindering the development of public-private partnerships. The African Agricultural Technology Foundation, which involves a number of NAE organizations and companies, is an example of a PPP program aiming to overcome these barriers (http://www.aatf-africa.org/) (Beintema et al., in press). Another illustration of the gap in AKST resources between the developed and developing world are the numbers and members of the professional societies involving economists: in 2001 there were 354 associations, only 44 of which were in developing countries (Ryan, 2002).

There are different interpretations of the developments in agricultural international R&D in recent years. The meta-evaluation of CGIAR conducted by the World Bank concluded that CGIAR's productivity-enhancing research has had sizeable impacts on reducing poverty but that further improvements in agricultural productivity will be critical to meet the Millennium Development Goal of halving poverty by 2015 (World Bank, 2003a). The mixture of CGIAR activities was criticized for not reflecting its core competence as was its reduction in funding for productivity-enhancing agricultural R&D (by 6.5 % annually in real terms between 1992 and 2001). During this period CGIAR increased its expenditures on improving policies and on protecting the environment by 3.1 percent in real terms annually while overall CGIAR funding declined by 1.8 percent annually. The share of restricted funding increased especially since 1998. The meta-evaluation identified the following factors as explaining the changing research mix and the increasing restrictions: (1) the unpopularity of germplasm improvement research in the constituencies of some key donors, (2) the CGIAR's justified response to environmental pressures on soils and water created by the changes in farming systems during the Green Revolution, (3) growing environmental advocacy in donor countries, and (4) the weakening of many national agricultural research systems (NARS), which led donors to turn to CGIAR centers to fill the downstream national and local public goods gaps closer to the farmer. The meta-evaluation also identified changes in the funding processes of CGIAR since the mid-1990s, which resulted in reducing the influence of independent scientific advice, caused a transformation of CGIAR's authorizing environment from being science-driven to being donor-driven, and a general shift from producing global and regional public goods toward providing national and local services (World Bank, 2003a).

Falcon and Naylor point out that CGIAR funds only about 3% of the total global agricultural R&D expenditures and that national agricultural research programs (NARS) also have to take a share of the responsibility for what happened in Africa. They see the larger issue as the question of scale: total agricultural R&D for the whole of sub-Saharan Africa was only around $1.5 billion and even this funding has become more and more irregular and donor-dependent. Globally, the real value of total development aid to agricultural R&D in the late 1990s was only 35% of that of the late 1980s (Table 2D, 6) (Falcon and Naylor, 2005). For example, agriculture's share of the total World Bank's lending fell from 25% in the mid-1980's to 10% in 2000 (Figure 2D, 12). The World Bank has also lost almost half of its technical staff working on agricultural development during that period (World Bank, 2003). Falcon and Naylor (2005) suggest that these declines were mainly due (a) problems with integrated rural development projects in Africa in 1975-1985, (b) lower real food prices adding to the problems of finding socially profitable projects, (c) the move to a country assistance strategy with emphasis on returns within three to five years, a time frame not appropriate for some investments such as public goods in agricultural infrastructure and research, and (d) food and agriculture receiving generally less attention as the foci moved to other areas of development. Agricultural development has faced similar changes with other aid organizations, e.g. USAID (Figure 2D, 13). Falcon and Naylor (2005) hypothesize that certain false assumptions applied in international aid for R&D during the last two decades collectively contributed to the current food security problems, in particular, that: (i) solving the world food supply problem would simultaneously solve hunger and malnutrition problems; (ii) international donors could reduce investments in productivity-increasing research serving poor households; (iii) agricultural development in poor countries would result in reduced markets for rich countries; (iv) it would be more efficient to focus development-aid efforts on democratization and other political variables than to focus on poverty, hunger and economic development in the countryside; and (v) agricultural and rural development in poor countries could be side stepped in the development process.

[Insert Table 2D, 6: Agriculture's share of overseas aid (Source: CGIAR Science Council, 2005a)]

[Insert Figure 2D, 12: Decline of World Bank lending to agriculture in the 1990s (World Bank, 2003)]

[Insert Figure 2D, 13: US overseas loans and grants 1980-2003 (millions US dollars) (Falcon and Naylor, 2005)]

In conclusion, there has been a widespread scaling back in investments in public R&D in agriculture among rich countries although this been balanced to some extent through funding of agricultural R&D through non-traditional sources. There has been a shift from public to private agricultural R&D and a shift in governmental spending priorities (CGIAR Science Council, 2005a). Inevitably, this will affect productivity prospects in NAE and spillover of ideas and technologies to poor countries. Rich-poor country linkages may weaken due to recent developments in IPRs and biosafety regulations. In addition, the current trend in NAE agricultural R&D away from staple foods to food quality and medical (including functional foods and gene-tailored diets) and other industrial applications of food commodities may contribute to a slowdown in sustainable productivity gains applicable to poor countries and thus to decreased benefits for them.

2D.1.4.4 Changes in structures and management

There has been a general trend in OECD countries from the traditional model, where an agricultural ministry had sole responsibility for agricultural higher education, research and extension, towards a model with a ministry coordinating overall policies of KST. Especially agricultural higher education has moved to ministries overseeing higher education more generally, with some exceptions (such as Sweden where maintaining integration within AKST was considered most advantageous) (OECD, 1999). In the latter group, special coordination mechanisms between AKST and KST have often been developed.

Universities and research organizations in NAE have to a large extent retained their disciplinary structure and indeed new disciplines have emerged. In the CEE, since the break-up of the Soviet Union, more demand for extension services has emerged to compensate for the disappearance of the centralized chain-of-command system (Miller et al., 2000). The disciplinary structure of NAE universities and research organizations has been complemented by separate, issue-centered research institutes and the functions by cooperative, integrated educational and research programs. It has been predicted that the traditional, administration-oriented system of faculties based on basic sciences may disappear (Väyrynen, 2006). The numbers of students in food and agriculture related subjects decreased in North America and Western Europe during the 1990s, a process that has continued into the present century. These disciplines are under increasing budget pressures at universities as well as at other research organizations. Also, food and agriculture has lost its important role in development studies at least in US universities (Falcon and Naylor, 2005). The situation in the CEE is different. At least in Russia the number of agricultural students increased by 50% from 1995 to 2000 (Miller et al., 2000)

Public agricultural research systems in NAE vary in terms of who funds, manages and performs research. Changes in scientific, economic and political factors have caused managers of national research organizations serious problems about how the organizations should be restructured over time, especially in face of policy inertia and increased costs (Read et al., 1988; Alston et al., 1998). In the UK and the Netherlands, for example, the public agencies involved with carrying out research have been consolidated and for some important parts commercialized. In the Netherlands, the share of private funding of Wageningen University and Research Centre rose from 25% in the 1970s to 40% in the mid-1990s, and the research was rationalized and oversight streamlined. In the UK, the number of publicly funded research institutes fell by more than half during the same period. The agricultural extension services were increasingly commercialized or privatized in several countries in NAE, e.g. in the UK, France and the Netherlands (Read et al, 1988; Labarthe, 2006; OSI, 2006). The changes were usually temporarily linked with the change to more market-oriented 'laissez-faire' governmental policy philosophy.

Comparatively little structural change has taken place in the public research system in the US until recent years. Historically, the US agricultural research system has been characterized by a decentralized, state-led structure, which fosters geographically specific applied research (Schultz, 1971; Huffman and Evenson, 1993). While the Federal Government provided about the half of all the funds during the last 50 years, state institutions have played an increasingly important role in funding and conducting state-level research. Since 1948 the State Agricultural Experiment Stations (SAES) system has been a considerably larger research enterprise than the USDA. In recent years, the proportion of the public agricultural funds spent on federal in-house research has declined to less than 30% (Rubenstein et al., 2001). The major force behind increasing the state share was matching federal funding with other (including state) funding. Farmer support for the US public system of research and extension is high although research suggest that the goals of some programs may be at odds with many farmers' needs and that there is a bias in the types of farms benefiting from land grant university resources, with smaller and diversified farms being largely underserved (Ostrom and Jackson-Smith, 2005). Fears of bioterrorism in the US led a few years ago to the creation of a National Institute for Agricultural Security (NIAS) to facilitate communication between the federal research system and the state-based agricultural research system (Nipp, 2004).

The changes towards more managed competition in agricultural research and from formula funds to competitive grants have been uneven and the institutions formed are country-specific. In the US the trend towards competitive grants in public agricultural R&D was slower than in other OECD countries, representing only 3% of the public agricultural R&D funds in 1995 (Alston et al., 1998) and 15% of USDA-funded state-level research at the end of the 1990s (Rubenstein et al., 2001). Usually allocation is based on *ex ante* claims (proposals) rather than *ex post* assessments about what was achieved. Allocation of funds to competing programs or institutions is at present based on frequent program proposals and reviews. The role of industry has increased in both funding and setting criteria for public funding, and notable shifts towards environmental and food safety issues have taken place.

The increase in managed competition has caused fundamental changes in AKST. It has substantially contributed to prioritization according to the interests of funding agencies which may reflect interests of governmental policies, commercial interests (farming community, large companies, etc), NGOs and other stakeholders who are represented on the boards responsible for project evaluation and resource allocation (see also Section 2D.1.4.5). The main intentions of the shift towards more competition were to ensuring high quality science and high overall productivity. However, the shift has also caused other fundamental changes. Because of the changing objectives and priority fields of the financiers and varied sources, the opportunity for specialization and competence building for experts and facilities has been reduced in areas where there is no sustained funding, even if there are high pay-off potentials. The trend towards more short-term contracts (usually limited to three years or less) has improved accountability (Nickel, 1997) but has had a number of negative impacts for AKST. Research has been increasingly directed towards laboratory work rather than the field. There has been less opportunity for empirical studies on sustainable agri-food systems with their inherent long-term perspective. It has been hypothesized that this may partly explain the shift in the focus of life sciences towards research into biotechnology (Buhler et al., 2002).

Education as well as managed competition, peer-review in project evaluation and priority setting by scientific journals have all played a significant role in strengthening the disciplinary paradigms and increasing method-orientation in science. Use of the most advanced, disciplinarily appreciated methods has become a crucial precondition for funding, journal publications and career development, often overruling the strategic objectives and practical relevance of the work. These changes had significant consequences for international AKST. Falcon and Naylor (2005), for example, claimed that development as a field within economics is disappearing due to “the path-dependent and disequilibrium nature” being at odds with the mathematical directions of the present-day economic theory.

Since the establishment of international agricultural R&D, the membership of CGIAR has increased from 18 to 64 countries, and the number of CGIAR centers grew to 18. The main enlargement in the 1970’s was linked to a wider coverage of commodities and the increase in the 1980’s was linked to the new focus on sustainability. A crisis occurred when some major donors reduced their CGIAR contributions due to domestic budgetary problems. The possibility of restructuring the CGIAR system (including reducing the number of centers) was considered. A visioning exercise was undertaken in 1991 to define future directions of CGIAR research and the type of organization required to increase effectiveness but no agreement was reached. The number of centers was only reduced to 15 and instead, steps were taken towards refocusing the research agenda on agriculture, poverty and the environment (CGIAR, 2006), and towards increasing transparency in the CGIAR system. Ten “southern countries” joined the CGIAR during and after the renewal program ending the practice of selecting “regional representatives” through the FAO. In 2001, a programmatic approach as well as a management and knowledge system were adopted, which involved increased participation of stakeholders and cooperation between the centers. The Technical Advisory Committee (TAC) was replaced by a smaller Science Council, which has the task to ensure relevance and science quality, mobilizing of international experts and assessing the impact of CGIAR research.

The CGIAR System as a whole has been reviewed four times. The latest review was the meta-evaluation by the World Bank (2003a, b) described above (subchapter 2D.1.4.3.3). One conclusion of the review was that changes in the funding processes of CGIAR since the mid-1990s resulted in changing CGIAR’s authorizing environment from being science-driven to being donor-driven, and a general shift from producing global and regional public goods toward providing national and local services. CGIAR management was streamlined in recent years and, rather than increasing participation, the World Bank claimed a more strategic leading role for itself in CGIAR with creation of a legal entity covering CGIAR’s central oversight and fund allocation functions (World Bank, 2003b).

2D.1.4.5 Influence of beneficiaries

There have always been different views of reality and behind them different normative visions of the desirable characteristics of a target food system and a target world to be promoted and sustained (Thompson, 1992). The values and meanings that are given priority depend on the economic, social and cultural circumstances and the political contexts of individuals and groups (Visser, 2001) and the size and power of different interest groups can have a major impact on the funding for and direction of AKST (Beintema et al., in press). Already in the early 1970's different views existed amongst decision makers about whether either high-tech agriculture or increasing the productivity of small-scale subsistence agriculture was the most appropriate strategy to achieve food security (Falcon and Naylor, 2005). Instead of seeking a black or white answer different approaches are likely to be appropriate for different situations and regions.

An important factor in making development research relevant to the target group and for successful adoption of R&D is to have strong links between research organizations and the people who are meant to use the results. This is especially important in international AKST where differences between economic, social, cultural and political circumstances are more pronounced (Buhler et al. 2002).
The establishment of the agricultural research stations and similar institutes in NAE in the first half of the 20th century indicates that research was conducted on the basis of farmer participation. The same is true of the early commodity-based stations run by private enterprises or by the government. This linkage was strengthened by the fact that many of the earlier agricultural scientists came from the farming community. During the Second World War and thereafter, the top-down emphasis and governmental intervention in R&D increased to ensure food security. Even during this time farmers' interest in guiding R&D was strong, and they had a major influence in policy (Buhler et al., 2002). In the latter part of the 20th century, the influence of farmers in public R&D diminished while that of larger companies increased. Levy boards remain one avenue through which farmers exert influence on agricultural research agendas (Accenture, 2007). More fundamental research was carried out especially in the 1980s for various clients and public goods and at the same time there has been a general shift in emphasis towards a focus on wealth creation. There is also concern that more fundamental as well as applied research is not made available in the public domain due to the increased extent of research being conducted and funded by industry, which inevitably is interested in confidentiality to protect investments and stay ahead of competitors (Buhler et al., 2002). In recent years farmer participation in the development of AKST has increased again in NAE (Romig et al., 1995; Walter et al. 1997; Wander and Drinkwater, 2000; Dik, 2004; Groot et al., 2004; Morris, 2006; Ingram & Morris, year, 2007).

Public consultation processes have been extended to include a wider range of voices in the setting of agendas for publicly funded agricultural research in recent years (OSI, 2006). There has been a switch of funding from activities that support farmers to activities used to control farming business and to address issues of externalities and public goods. The emphasis on control is to a large part a result of concerns about issues such as BSE, foot and mouth disease and Avian influenza.

The number of civil society groups (or non-governmental organizations, NGOs) in Western Europe and North America has increased dramatically since the end of the Second World War, with most of this increase post 1970. Civil society groups include e.g. community groups, women's groups, consumer groups, environmental organizations, labour unions, indigenous peoples' organizations, charitable organizations, faith-based organizations, professional associations and foundations. At a national level, civil society groups are more visible in Western Europe and North America than they are in Eastern Europe. However, this may change in the future as the general tendency towards liberalisation continues. The growth in number and influence of civil society organizations in the past 25 years has meant they are now included in consultations on national (and also EU) agricultural policy as stakeholders. At an international level, there has been a policy to invite civil society groups to meetings of UN agencies, notably UNEP. However, their involvement has generally been limited to observer status, although there are some plans to enhance civil society's engagement (UNEP, 2002). The FAO has a formal list of NGOs it works with and also an informal list. Consultations are held with civil society groups at a regional level. However, many civil society organizations doubt the extent of civil society influence on agricultural policy, compared with that of agricultural business interests. Others are concerned that the pressure applied by single issue NGOs on agricultural policy is not always evidence-based and often only represents small segments of society.

The current research climate has been criticised as being characterised by short-term perspective and responsive science and as being dominated by industrial and political influences with only a small role for farmers and consumers in setting of agendas setting (Buhler et al., 2002). Others see the increasing influence of consumers and NGOs on the setting of agendas as one of the main changes in influencing the evolution AKST in recent years (see subchapter 2B). There is also mistrust amongst consumers and some NGOs that farmers and farmer organisations have too much influence on the setting of agricultural research agendas.

The colonial period was characterised by a top-down approach and a focus on cash-crops with little interest in subsistence farming (2D.1.2.2). During colonial times, few people with influence in agenda setting came from developing countries. After the end of the colonial period, the national R&D structure, methods and even personnel changed only slowly (although the focus turned more to food crops) and thus linkage of agricultural R&D to clients was weak. Extension tended to be transfer of technology–oriented and one-directional, leading sometimes to technologies inappropriate for resource-poor farmers and to low uptake in resource-poor communities, although in some regions this approach could be very successful (2D.1.2.2). Indigenous agricultural systems received negative rather than positive attention (Boserup, 1965). Since the late 1970s, participatory approaches involving farmers have become more common and part of the mainstream but many scientists remain sceptical and participatory approaches still face many barriers (2D.1.3.3). According to Becker (2000), in CGIAR participatory approaches were restricted “to a few pockets” as the mainstream of biological scientists within CGIAR remained highly sceptical. Since that time the CGIAR centres have been under increasing pressure to institutionalize participation although there have been problems (2D.1.2.2; 2D.1.4.3). It has been questioned whether true equal participation of resource-poor farmers and rural populations in the agenda-setting process for AKST has been achieved in developing countries (Buhler et al., 2002).

The international donor organizations and contributing governments are seen as influential beneficiaries and clients, and their importance has increased further during the last decade, due to the increasing constraints set by donors in respect of the use of funding (2D.1.4.3).

In conclusion, the voice and participation of NAE policies outside NAE have increased since the Second World War. The voice of large private businesses as well as NGOs and donor organizations have also increased, although more recently. The changes that have occurred in the modern food and agricultural system and in rural livelihoods pose major challenges for public-sector agricultural research and education in terms of equity and integration. Tripp (2001) concludes that technology development by public funding has to take into account the increasing privatization of technology provision, the increasing complexity of economic circumstances and significant diversification of livelihood strategies. It has to support both emerging commercial farmers engaged with global commodity chains for information- and skill-intensive innovations, the semi-subsistence, often part-time farmers requiring simple, sometimes labour-saving technologies, as well as organic farmers. In addition, the cross-sectoral and multi-occupational character of contemporary rural livelihoods has to be approached in efforts to reduce rural poverty (Ellis and Biggs, 2001, BANR, 2002).

2D.1.4.6 Consequences of the changes in structures and funding

The consequences of the changes described have been critically studied and discussed. Questions posed from an economic point of view include: Have the changes improved the economic efficiency of R&D? Has the emphasis on topics changed, such as farming and environment or processing, or between basic and applied research and extension, or among programs and institutions? Are administrational and transaction costs lower? Other questions that need to be posed include: Have there been changes in who now benefits?

At least since the 1950s, studies have shown an unusually high productivity of public agricultural research (e.g. Schultz, 1953; Griliches, 1958; Ruttan, 1982; Huffman and Evenson, 1993; Fuglie et al., 1996;

Alston et al., 1998) with no evidence of a decline (Alston et al., 2000). This would have justified an even higher share of funds allocated to public agricultural research. However, budget pressures have induced administrators and public decision makers to reduce budgets while striving to avoid a significant loss of productivity. To improve productivity the share of funding given out as competitive grants has been increased since the 1970s (Rubenstein et al., 2001; Huffman and Just, 2000). Also, the increasing role of the private sector in management of the public R&D has caused concern. In response, debates about how to foster, organize and manage agricultural research (as well as of research in general) have intensified during the 1990s (e.g. Buttel, 1986; Just and Huffman, 1992; Alston et al., 1995, 1998; Huffman and Just, 1994, 1999, 2000). This debate builds on earlier discussions surrounding controversial topics such as national priority setting, central planning of agricultural research, over-organization of institutional research, top-down approaches, requirements for elaborate documentation and justification of research, and whether research can/should be treated as a routine activity (Schultz, 1980, 1982, 1983, 1985; Huffman and Just, 2000). Schultz (1980) suggested that "although money, facilities and competent agricultural scientists are necessary to do worthwhile research, it is not a routine activity. It is, indeed, a subtle, elusive human activity that is difficult to foster, promote and maintain". Other topics discussed included the character of agricultural research as innovation and the difference between setting efficient incentives and organizational structures for industrial production/marketing and innovation processes. Huffman and Just (2000) suggested that "because academic research is undertaken to obtain discoveries and advances in knowledge, it is innovative activity. Hence, incentives and organizational structures are very important to an efficient and effective organization of agricultural research". Rubenstein et al. (2001) showed empirically that the US competitive grants focussed more on basic research and were distributed among fewer states than other instruments.

Competitive grants are by many scientists seen as leading to an increase in scientific quality. They have in some cases also been successfully used to lever a change or paradigm shift in organizational behaviour (Sutherland et al., 2004). However, others are critical of the increase in competitive grants. Huffman and Just (2000) applied principal-agent theory and presented a model of optimal agricultural research management emphasizing the *ex ante* uncertainty of research pay offs. They compared three types of funding, management and prioritization: *external grant funding, contract between scientist and external funding agency, and formula/program funding*. According to these authors the current trend towards external grant funding at the expense of formula/program funding (and more direct intervention in the research process by administrators) may be counter-productive. This was due to (when moving from formula/program funding to research grant funding): i) scientists' time being used for proposal writing/evaluation and signalling activities rather than for more productive activity; ii) compensation based on a proposed budget rather than research output; iii) reward for quality proposals rather than quality outputs even though they are imperfectly correlated; iv) compensation is determined *ex ante* eliminating quality from the incentive scheme; v) the risks of conducting research imposed unduly on scientists; vi) the need for scientists to focus on writing grant-proposals rather than on conducting research; and vii) erroneous judgements sometimes made by review committees about project potential. Review committees also frequently impose relatively narrow views on research approaches thus eliminating the benefits of sampling diversity. In their analysis, the risk of screening out more creative projects with a potentially higher payoff appears to have increased. If these conclusions are correct, the implications are significant, since the share of funding provided through competitive grants has risen dramatically in the last decade or two. As discussed above there is also concern about the associated increase in bureaucratization of science. An asymmetry exists in the sharing of transactions costs associated with external peer-reviewed competitive grant programs, especially when the average grant size is small and the average award rate is low (Huffman, 2005).

The potential of research contracts with external funding agencies may be increased if the contracts involve procedures, which focus primarily on incentive compatible reward structures (i.e. it is in the best interest of both the scientist and the administrator to voluntarily fulfil the contract) that emphasize research productivity and make unproductive monitoring unnecessary. The contract-based incentives for scientists should be quality-based rather than cost-based as far as possible as an incentive for quality encourages greater pay-offs when pay-off is uncertain. The pay-off of the project should be defined so that it broadly describes the desired goal/innovation whereas the procedures/route to the goal should not be highly prescriptive. The incentive should, as far as possible, take into account differences in ability/experience between scientists. The latter is, however, difficult to achieve in short-term contracts, which limits the applicability of this approach in practice.

Along with the declining program/formula funding of research institutions, recent trends foster more competition for budget funding, application of the short-term project formula, reduction of funds for technical research staff and more direct management of expenditures. In the principal-agent model for research incentives, these policy changes resulted in an immediate increase in the institutional risks of research. It has been suggested that an increase in risks of research leads to reductions in scientists' efforts, in the total R&D pay-off as well as in the expected net compensation of scientists. Huffman and Just (2000) argue that such policies may be counterproductive and a step back from earlier, less interventionist management policies. Alston et al. (1998) questioned whether the short-term benefits of these shifts outweigh the longer-term costs, also pointing to the competitive ability of R&D for human capital. Block allocations on the basis of reviews conducted at longer time intervals may be a way of reducing the transaction costs while still preserving a certain level of competition.

Already in the early 1970s the public agricultural research system in the US was criticized (by J. Hightower and colleagues) for benefiting the large farmers more than small farmers and for providing particular benefits to agribusinesses (Buttel, 2005). The rise in the role of the private sector (including the farming industry) in public R&D management in the last 15 years, which occurred through increased linking of private and public funds through levy schemes, joined funds and by inviting representatives of industry to join prioritizing committees and the increase in the share of private funding in the overall funding of agricultural R&D has aggravated these concerns. Problems associated with an increased influence of the private sector in the setting of public research agendas include the potential for biased benefits for certain sectors of the industry (Ulrich et al., 1986; Constantine et al., 1994) and may result in crowding out some industry research funds (Alston et al., 1998). Benefits include improved participation of stakeholders, giving farmers more influence in setting research agendas and a stronger focus on issues relevant to end users (Alston et al., 1998). The share of private sector expenditure in total agricultural R&D has increased to the extent that it exceeds public sector expenditures (2D.1.4.3) (Fuglie et al., 1996; Huffman and Just, 1998; Huffman and Evenson, 1993). This trend is seen by many as not benefiting society as it shifts the focus further away from R&D that could benefit resource-poor communities and small rural enterprises, reduce hunger and poverty and improve equity and social sustainability (BANR, 2002; Buhler et al., 2002). It is also perceived as having a negative impact on the sharing of knowledge not only in terms of near-market activities and production systems but also in terms of environmental advice (Read et al. 1988; OSI, 2006). There is a general feeling that the increase in public sector influence on agricultural R&D funding decreases rather increases the potential to achieve sustainable development (Buhler et al., 2002). The increased privatization of agricultural research has generated a new stream of agricultural research activism, including the anti-biotechnology movement which in parts contests corporate R&D on genetically modified crops (Buttel, 2005). The legislation introduced in the 1980s, enabled universities to patent technologies developed with public funding. It led to the rapid privatization of technology transfer, in which universities began to stress technology transfer that yields royalty income over gratis technology transfer. This change is seen by some as being to the detriment particularly of smaller farmers (Buttel, 2005).

The trend towards making public agricultural research facilities more cost effective had a positive economic impact where such rationalization took place in response to changes in scientific methods and to take advantage of new economies of size and scope. However, where “rationalization” was used merely as a justification for reductions public R&D investments, the impact could be negative or positive depending on whether the rates of return on the investments were higher than the marginal social opportunity cost of funds (Alston et al., 1998). There are concerns that rationalization has in some areas of NAE contributed to a serious fragmentation and weakening of the disciplinary research base and that the strategic planning of public sector funding organizations has not been joined up enough at a national level to help maintain crucial scientific expertise and facilities. The costs and time needed for re-building expertise have not been sufficiently included in the evaluation of areas of research considered for closure (OSI, 2006).

Reallocation of public research resources away from near-market research programs to environmental and food safety issues is widely seen as having provided social gains but there is so far no formal evidence available on the payoff to public R&D into environmental or food safety issues, and incentives to adopt results that yield social benefits are usually required to achieve a payoff at all (Alston et al. 1998).

Diversion of public resources towards agribusiness and food processing research (as happened e.g. in the UK) represents another potential downside to the recent changes in agricultural research policy in NAE. It is not yet clear whether projects funded in these areas approximate public good projects more closely than those they have displaced in the area of farm productivity and this shift of resources may have reduced the rate of return to public research investments (given that near-market agribusiness and food processing are characterised by relatively few firms with no evidence of market failures) (Alston et al. 1998).

2D.1.5 Development of public control of agri-food systems

The rise of different forms of control of agriculture has had profound effects on agriculture in NAE over the past 50 years. Bingen and Busch make the important point that standards from both private and public sectors shape innovation and technology in agriculture in multiple ways (Bingen and Busch, 2006). Although in recent years de-regulation is often held up as a policy goal and ambition, in fact in relation to product quality, risk, environmental standards, animal welfare and intellectual property standard setting by both private and public sectors determine the space in which producers and companies compete. Standard setting is done by government regulatory agencies, firms, international organisations such as Food and Agriculture Organisation (FAO) and the World Trade Organisation (WTO) and private voluntary organisations such as business associations.

The section that follows looks at different forms of risk regulation and intellectual property regulation in NAE. These two forms of regulation and changes in the way they are implemented and conceived of are particularly important in relation to agricultural inputs and major new technologies in agriculture such as biotechnology and nanotechnology.

2D.1.5.1 Development of risk regulation

In developing technology for agriculture, as in other areas of innovation, the products that eventually reach the market place, their public benefits and their commercial profitability depend on a complex set of interactions between scientific developments and industry strategies, policies to promote and to regulate innovation, and market opportunities, public and stakeholder attitudes and desires.

This subchapter illustrates interactions between public risk regulation and innovation, although national regulatory systems and international protocols are inevitably influenced by public and stakeholder pressures. From the broad range of public regulatory actions applied on agriculture and food systems, this subchapter takes two examples: pesticide regulation and regulation of genetically modified (GM) crops including intellectual property (IP) rights protection. The examples consider the links between these regulations the similarities and discontinuities in the regulatory systems as they evolved in Europe and the US, and the outcomes for the international competitiveness of agriculture on these two continents.

[Insert Text box 2D, 4. Example 1: Pesticide regulation in Europe and the US]

[Insert Text box 2D, 5. Example 2: Regulation of genetically modified crops]

2D.1.5.2 Intellectual property rights

Intellectual property rights (IPR) are rights awarded to individuals or organizations over creative works. They give the owner the right to prevent others from making unauthorised use of their property for a limited period. Intellectual property is categorised as Industrial Property (functional commercial innovations), and Artistic and Literary Property (cultural creations). Development of forms of protection of agricultural IPR includes patents, gradually expanded to protect the outputs of agricultural research and innovation, plant breeders rights (PBR) and copyright (Chapters 2A, 2B). A unique hybrid system of PBRs has evolved that provides a specialized form of IP protection and offers an alternative to the patent system (CIPR, 2002). The International Convention for the Protection of New Varieties of Plants (the UPOV Convention), which was adopted in Paris in 1961 and entered into force in 1968, has provided the basis for international harmonization in this regard.

The following text box (Text box 2D, 6), taken from the Commission on Intellectual Property Rights (CIPR, 2002) provides a more detailed picture of international IP architecture

[Insert Text box 2D, 6. The International IP Architecture: Multilateral, Regional and Bilateral Rules]

2D.1.5.2 Changes in policy goals

Supply driven policies

The Second World War left the agricultural and food sectors of most European countries in disarray. In the 1930's all sectors, including farming, had suffered in the Great Depression. During the war the emphasis of policy had been strongly on production in order to sustain the embattled economies. Throughout most of Europe production was severely disrupted by the war. Infrastructure facilities had been badly damaged. People, especially the younger and more productive workers, had been forced to leave their homes, often leaving farming to older members of the family. In all sectors there was a loss of skilled labor and a destruction of capital equipment. This disruption of the economy meant that countries faced acute balance of payments problems and were unable to afford large scale food imports. Food was scarce and rationed. By the end of the war the availability of food in Germany in terms of calories per head had fallen to 2000 and immediately afterwards it fell still further (Tracy, 1982).

The recovery of the agricultural sector in Europe was critical both in terms of food supply and because of the substantial share of real income that was generated in farming. The percentages of national income derived from agriculture varied greatly. In 1955 the share of agriculture in GDP was between 20% and 30% in Ireland and Italy, between 10% and 20% in Denmark, Austria, Netherlands, France and Sweden and between 5% and 10% for Belgium, Germany and the UK (OECD Statistics 1955-1968). The share of the workforce in agriculture varied even more widely. In 1958 within the emerging EEC 23% of the work force was in farming (European Communities Statistical Office, 1968). Contemporary national figures vary from below 5% in the UK to around 40% in Ireland and Italy.

The principal policy instrument used to stimulate production was price. Not only were price fixed at levels that would enable farmers to operate profitably but state support systems absorbed much of the risks of markets. As long as rationing existed, farmers received prices determined by the state. In some countries, such as the UK, an annual review took place within which the state of the industry and future prospects were discussed and prices determined for the coming season. This process gave farmer organizations access to government and gave rise to concerns that ministries of agriculture were sometimes seen as being dominated by the farming industry.

In Western Europe the industry recovered rapidly, thanks to substantial aid from the US under the Marshall Plan. By the mid 1950’s there was no longer a shortage of food, and there were early signs that this would be replaced by problems relating to production in excess of domestic consumption requirements. Memories of shortage and of the widespread rural distress of the 1930’s meant that governments were unwilling to allow prices to collapse. Two models of support evolved. The first regulated internal market prices by imposing restrictions and tariffs on imports and subsidizing exports. The second allowed greater freedom of trade and permitted market prices to fall but supplemented farmers receipts from the market by budgetary payments, known for example in the UK as ‘deficiency payments’. Both systems provided an assured return to farmers for their products based on government action.

Farmers were further helped by a variety of subsidies provided on inputs. These included specific inputs, such as fertilizer, fuel and machinery. There was also encouragement for specific farming practice, such as grants to plough up grassland in the UK and the provision of reduced price feedstuffs in Norway. The focus was on increasing output by encouraging the uptake of new technology (OECD, 1967).

In both North America and Europe extension services played a major role in disseminating new technology and in moving farmers towards a more business orientated approach to their activities. In the U. S. the Land Grant Colleges played a major role. In Europe the emphasis was on services provided by the state or regional authorities, often operating in conjunction with farmer co-operatives. In the centrally planned economies of Central and Eastern Europe shortages remained a problem longer than in the west and production was encouraged through targets for delivery and the provision from regional centers of services such as machinery.

In the uptake of new technologies the private sector played a major role. Seed companies developed new more productive varieties of major crops. The agri-chemical industry evolved new more effective forms of plant protection. Especially among pigs and poultry selective breeding produced varieties of animals that were highly productive and could be managed successfully in large-scale units. In veterinary practice the use of antibiotics both as growth promoters and to cope with disease secured higher levels of stocking and greater rates of weight gain. The underlying science was global, often emerging from publicly funded research. Major international companies played an important role both in fundamental research and especially in turning new understanding into profitable products (ICI, 1978).

By the time the Common Agricultural Policy was designed in the 1960's, shortages had disappeared in Western Europe but the fear of their return was still sufficiently present for governments to place a considerable emphasis on retaining production capacity. As price levels were negotiated it was easier to approximate to the higher levels than to fix prices at a point that would restrain production to market demand within the new Community. The combination of high prices and improving productivity led inexorably towards surplus. By 1968 the Commissioner for Agriculture, Sicco Mansholt, was proposing reforms to contain a burgeoning dairy surplus and to promote a more economically efficient structure of farming in the EU.[10]

Market driven policies

The transition from concerns about shortages to problems relating to surplus was a gradual process and to a substantial extent the mechanisms that had been established to develop and apply new technologies in farming remained in place. During the 1960's UK policy recognized a growing problem of excess supply: The deficiency payment system meant that when market prices fell substantial and unpredicted additional costs fell on the national budget. The policy response was twofold: first to limit the level of production that would be supported at the 'guaranteed' price and second to emphasize the need for greater efficiency in production.

Within the European Community the issue of surpluses increasingly dominated policy thinking from the late 1970's. There surpluses gave rise to the need to subsidize very large volumes of exports and to store large quantities of produce that could not be sold within the European market at prices that had been set by the Council of Ministers. The emphasis of policy swung from production to supply control and the use of devices such as quotas and set asides to limit the volume of output from EC farms.

[10] Le Plan Mansholt Communautés Européennes – presse et information Brussels 1968

The impact of this on AKST was gradual. Substantial funds continued to be allocated to agricultural research and to extension. However, in several countries there was an increasing view that extension and research should be funded by the industry as was the case in other major sectors. Charges were made to farmers for extension services that related to increased profitability on the farm. In Europe national extension services tended to be privatized. Research funding continued to come from the state but an increasing share was expected to be derived from levies on the industry.

The focus of research also shifted. Whereas the traditional target had been quantity, now quality became an issue of growing importance. Two factors contributed to this shift in emphasis. First, the food industry had become more concentrated, more sophisticated and, facing a market that in volume terms was growing very little, sought for differentiation through quality. Differentiation could be achieved in a variety of ways. Organic farming grew in response to consumer perception. Product identification by region could secure sales and protection was given by legislation to particular 'regional' designations. Some farmers joined with retailers to market animal products on the basis of superior animal welfare on the farm.[11] Policy sought to help farmers to adjust via aids to encourage the development of producer groups (Fennel, 1997).

2D.2. Impacts of NAE AKST in relation to the IAASTD Goals

In this part of the chapter we seek to summarize how the contribution of NAE AKST to the evolution of agri-food systems impacted on hunger, poverty, nutrition, health, rural livelihoods as well as social and environmental sustainability in the past and to set the scene for a consideration of the development challenges and the role of AKST in meeting the IAASTD goals in the future.

2D.2.1 Impact of increased production on poverty and hunger

Hunger is much more common in the developing world than in North America and Europe. Even so it is clear that under-nourishment also occurs in that part of the world and in the Commonwealth of Independent States[12] (Table 2D, 7). The availability of food is a necessary but not sufficient condition to remove hunger. The fact that the elimination of hunger has not been achieved is to a large extent (in common with other regions that suffer food insecurity) the outcome of societal failures, war, economic dislocation and income inequities.

[Insert Table 2D, 7: Prevalence of undernourishment in the total population (%) in different parts of the world]

[11] RSPCA information on food assurance schemes http://www.rspca.org.uk/servlet/Satellite?pagename=RSPCACampaigns/Consumers/Foodassuranceshemes&articleid=1099596651860 (accessed 28 Feb 2007)
[12] The CIS includes Azerbaijan, Armenia, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Uzbekistan and Ukraine

AKST has contributed to increased crop and livestock productivity in North America and Europe (Chapter 2A), which has provided the basis for improved wealth and health of the people in this region. Production has also increased in aquaculture although fish caught at sea remains the principal source of fish in human diets. However, hunger remains a problem for the poor. Poverty remains a problem in all societies but in North America and Europe this seldom results in hunger but can give rise to diets that are of low quality and lead to poor health. It is primarily those who slip through the net of social support systems who go hungry. These can include significant numbers of old people, children in large low income households and people who have excluded themselves from society. Hunger can also arise because of the misuse of income – particularly among people who are habitual drug users. The remedy for such situations is not AKST but a combination of education and social support systems.

In the developing world, too, poverty is the primary problem. There, however, the state is not able to provide the same level of safety net that exists in richer societies. Food security in developing countries thus depends for many on informal family arrangements, the existence of entitlements allowing food to be provided even if money is not available. Such arrangements are strongly linked to stable social situations. As these are threatened by conflict or simply by the increase of farm size, such arrangements can fail resulting in more people going hungry. Increased production and improved AKST within such societies help towards relieving the problem but are not themselves a solution. Sometimes growth achieved in production focuses on export markets producing crops that offer relatively little nutrition to the local population while competing for resources with local farmers. However, given the importance of farming within the economies of most developing countries, increased production based on more productive technologies provides a basis for economic growth. The benefits of this may, however be unequally distributed. AKST may contribute to relieving the problem by providing understanding about causes of food insecurity and options for food security in different societal contexts. Agricultural systems may provide more food security, if AKST assists them to broaden their scope and increase integration of approaches (e.g. in terms of agronomy, ecology and sociology).

The increased production fostered by AKST in North America and Europe has also provided food for other areas of the world. Sometimes this has been supplied to depressed world markets, further lowering the ability of farmers in developing countries to compete and discouraging investment in new technologies. Food produced in North America and Europe has been used to alleviate famines and other food shortages in times of crisis. There are problems with ensuring that such food reaches those in greatest need given the lack of infrastructure in many of the poorest countries of the world. There is also a danger of a dependency culture emerging as governments look to subsidize imports to feed urban populations and neglect the development of their own agricultural sectors.

The provision of food in emergency situations does not represent a solution to the problems of poverty or hunger in the long term. The expansion of production in developed countries, supported by policies that limit access to their markets and subsidize exports has been a major area of conflict within international trade negotiations[13]. The lower prices these create undermine markets within developing countries as well as for exports. Investment in agriculture and in the infrastructure of transport, power supplies and processing equipment is discouraged. As a result the impact on economic growth and on the alleviation of poverty is far reaching. Rural households can find themselves unable to provide enough food for subsistence from their own land and many of the most vigorous and entrepreneurial young people go to the towns where they often compete for low paid employment.

It should be emphasized that these undesired outcomes are to a large extent the result of policies that maintain internal prices by subsidizing exports and limiting access to domestic markets. AKST is applied in ways that reduces the resource costs, measured at market prices, of meeting demand. Where supply outstrips demand as a result of higher productivity, society can only be benefit if some resources move from old to new uses. Simultaneously the effects of AKST are distributed in a diversity of ways. For example, when food prices are lower, pressure on environmental goods such as water or wild species is likely to be changed. While some producers and many consumers may enjoy an increase in income others, particularly small traditional producers, may suffer loss. Similarly, if more efficient methods mean that the same amount of water or fertilizer can support higher levels of output, the environmental impact of a given level of production may be reduced. The cause-effect relationships are, however, very complex. The impact on incomes will be critically dependent on the performance of the economy as a whole. The impact on the environment may be made more damaging if what results is more an unmarketable output, or an increased pressure on some fragile resource. This complexity makes any simple judgment of the effect of AKST on livelihoods and equity misleading. Critical will be the state of the economy concerned, the sufficiency of its social security system, the availability of education and training both for technology uptake and to address any dislocations, and access to capital for new investment. Overall it is probable that all these conditions will be more readily filled in countries that are affluent than in those that are poor, although progress could be made by making AKST more contextual and through advances in more appropriate technology. There are also means to adjust the societal and capital situation to the requirements of agricultural technology (e.g. the Grameen bank for the poor in Bangladesh[14]). Such models could be identified and distributed through AKST, as financing is an essential part of food systems.

[13] For an account of Export Subsidies and WTO see http://www.wto.org/english/tratop_e/agric_e/negs_bkgrnd08_export_e.htm
[14] http://www.grameen-info.org/

2D.2.2 Impact of knowledge transfer on hunger and poverty

Knowledge developed in North America and Europe developed on the basis of the resource base, the economic structure and the political requirements of that region. Transferred to developing country environments it is often not effective in either physical or economic terms (see above). However, it is in these areas that the most acute problems of poverty and hunger are found. Much of the technology that has succeeded in the developed world is dependent upon a sophisticated infra-structure. Attempts to apply this where such resources are missing can lead to costly mistakes. For example tractors which enable cultivation to proceed quickly when conditions are right add much to productivity in Europe but they require a back up of spares, of fuel and of expertise when a component fails. Without this back up they rapidly become useless. Similarly, many improved plant varieties designed for developed countries are high-yielding because they are able to make good use of additional nutrients supplied by fertilizer and are protected from pests by chemical plant protection products. Where these are missing the improved product can prove less economically viable than the traditional seed it replaces.

This does not mean that the advances in understanding that underpin AKST in the developed world are irrelevant. Many of the techniques used in developing improved varieties are applicable. The understanding of plant and animal diseases may be essential if scientists in developing countries coping with different species are to devise appropriate strategies. Recognition of this has led governments and aid agencies to invest in training scientists from developing countries in NAE. It has also provided the rationale for investment in creating research facilities and educational institutions within developing countries, where the scientific principles that have enabled productivity to grow can be applied to enhance production there. The effects of this are discussed in Chapter 2C. What resulted was described as a Green Revolution (2D.1.2.2 and Chapter 2A). In economic terms this approach had its successes. Output rose and per capita food supplies were maintained or improved despite substantial increases in population. However, in terms of the goal of reducing poverty and hunger a key criticism of the Green Revolution was its impact on the distribution of income. The need to use imported inputs, fertilizer and pesticides, meant that many small farmers became indebted and lost their land. While lower prices benefited urban consumers, farmers who could not make use of the new technology suffered a real reduction in income. As in the developed world so in the developing world the application of AKST changed the underlying economics of food production, increasing output but, at the farm level, providing employment and incomes for fewer people. In prosperous economies this disturbance, although uncomfortable was transitional as people found new jobs off the farm. In countries with fragile, low income economies this process did not happen so quickly and poverty and hunger increased for many of the rural poor.

2D.2.3 Improved nutrition and human health

The availability of a satisfactory quantity of food is an important but not sufficient condition to ensure adequate nutrition. For many poor people, food is today more abundant than at any previous time. Although hunger remains a grave problem more people in NAE are better fed and have a wider choice of food than at any time in the world's history. A growing problem is 'over consumption' diets that lead to bad health through obesity and chronic diet related diseases. These are associated with both the volume and type of food consumed (Chapter 2A). Communication has a major role in increased awareness of the risks involved. Despite these problems it is noted that globally people are living longer and a major issue in NAE is the implications of longer life for pension policies (Chapter 1).

2D.2.4 Environmental sustainability

One way to describe the function of an economic system is that it is a mechanism to take resources in existing form and transform them into outputs that form part of what consumers demand. The food system includes not only what happens on farms but all the activities involved in processing, distributing and preparing food for consumption. Similarly forestry, a major land use has to be assessed not only in terms of what happens on the land but must include changes in the products produced and the processes used to make them available. How these industries behave reflects our understanding of natural processes and of what consumers are willing and able to pay for. The inescapable conclusion is that both the methods used in the wider food chain and in forestry have been changed by the development and application of AKST since 1945.

The evidence reviewed herein indicates that for many people the existing system does not enable the needs of the present and local population to be met without compromising the ability of future generations or populations in other locations to meet their needs. Many of the changes made possible by AKST depend upon the greater use of resources, including water and nutrients. Some of the effects of using technologies made possible by AKST are to pollute the environment including air and water, and to enhance anthropogenic climate change.

Not all the effects are adverse. For example Chapter XXX describes that AKST has enabled the use of minimum tillage, the better use of fiber in paper making, the mechanical cleaning of water used in aquaculture, etc. Much of the criticism does not explore what would be the environmental impact of alternative ways of meeting the demand for food nor the implications for poor people and hunger if these systems meant that the price of food would be substantially higher. However the anxieties expressed are serious and need to be taken into account so that policies can seek solutions that are more sustainable. AKST can help to identify favorable alternatives, their impacts as well as policies required to promote their use.

A major concern is the loss of biodiversity. As areas devoted to agriculture have increased, areas available for wild flora and fauna decreased. The development of effective herbicides and insecticides reduced populations of wild plants and insects on farmland as well as birds and mammal species that depended on them. Breeding efforts led to economic success of a limited range of varieties of plants and animals and which started to dominate commercial production (see Chapter 2A). Differing views about the potential environmental impacts of GM crops and animals continue to be a major issue (Chapter 2C), which has been reinforced by the different approaches to their regulation in NAE (see Subchapter 2D.1.5.1).

A second concern is that technology used in agriculture and the food system contributes to climate change. Part of this is the dependence of the system on non-renewable fossil fuels that release substantial amounts of CO_2 into the atmosphere. The movement of fresh food by air transport is seen as a significant contribution to the accumulation of greenhouse gases. The cultivation of land can release nitrogen held within the soil. The use of fertilizer and pesticides adds to the amount of greenhouse gases released (see Chapter 2C). Not all the nitrogen and phosphorus applied to agricultural fields is taken up by the crops for which it is intended. The increased number of cattle made possible by the use of AKST also contributes substantially to the release of greenhouse gases (see Chapter 2C).

A third concern is pollution of water. This arises both from fish farming and from the more intensive cultivation of arable land (see Chapter 2A). There has been evidence of environmental pollution caused by salmonoid aquaculture production sites in Europe. Phosphorus from agriculture can contribute to eutrophication, or over fertilization, of fresh waters, and of coastal marine waters. Increasing levels of nitrogen use on farms have increased the nitrate content of drinking water imposing additional costs to bring levels down to a point thought to be safe for human health. Irrigated farming can not only deplete soil water reserves but can also add to pollution as water used in production finds its way into rivers and streams. The excessive use of water for irrigation can also lead to salinization of ground water, reducing its usefulness for production.

A fourth major concern is soil erosion. Accelerated erosion by running water has been identified as the most severe threat to soil in Europe (Kirkby et al., 2004), and is on the increase (Van-Camp et al., 2004) as noted in Chapter 2C. Mechanical cultivation enables farming systems that can loosen soils making them vulnerable to wind blow and allow cultivation on slopes that would otherwise be terraced or left in grass. In areas where climate change has led to long periods of drought the risks of erosion have grown.

2D.2.5 Response of policy to environmental challenges

The period from the 1960's to 1980's was characterized by specialization, increased farm size, intensification and greater use of external inputs made possible by the use of AKST. Domestic animal production in certain areas of Europe increased significantly much based on imported feed. Animal production was to a considerable extent separated from crop production. During the 1980's and 1990's the environmentally unsustainable impacts of this system of production were increasingly recognized. Since the 1990's, agricultural policy has sought to take account of and overcome negative environmental impacts and harmonize environmental, social and economic objectives.

The policy response has taken three forms, regulation, support for environmentally preferred agricultural practices and a switch of support from production to rural development based on minimal environmental standards embodied in cross compliance. Within the EU the latest reform of the Common Agricultural Policy (CAP) demonstrates the radical nature of this transformation. Whereas the original CAP was made up mainly of commodity regimes that supported domestic prices at levels well above those in world markets, in the reformed CAP prices are determined in the market and support given to farmers is decoupled. In effect farmers receive this support payment, provided they meet minimal environmental conditions to keep land in good agricultural condition, regardless of whether they produce anything for sale at all. Additional support is to be given to the production of energy crops. Over and above this, member state governments can modulate payments received by farmers to support rural development which includes the environment, animal welfare and help for farmers to meet new higher EU standards.

Regulations to mitigate the impact of farming practices such as the nitrates directive[15] and the increasingly stringent regulations on the disposal of waste[16] have been introduced. The implementation of environmental improvement schemes is largely left to member state governments subject to the approval of the European Commission. In the UK, for example, there are a variety of existing schemes including the Hill Farm Allowance, English Woodland Grant Scheme, Energy Crops Scheme, Rural Enterprise Scheme, Vocational Training Scheme and Processing and Marketing Grant Under the reformed CAP the government has also introduced a points scheme whereby farmers who undertake work of particular environmental benefit may receive additional direct payments.

2D.3. Lessons Learned

Paradigm shifts have been major drivers for the changes that have taken place in NAE AKST after the Second World War. Further paradigm shifts now seem to be a precondition for further reducing hunger and poverty, improving nutrition, health and rural livelihoods, and facilitating social and environmental sustainability. Institutional and organizational changes in AKST will be important factors in helping to meet these goals of the IAASTD. The issue is not only to generate more AKST relevant to the IAASTD goals but also to improve access and use of AKST. In this part of the chapter we seek to summarize lessons learned from the last 60 years.

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[15] Directive 91/676/EEC on nitrates from agricultural sources, http://ec.europa.eu/environment/water/water-nitrates/index_en.html
[16] See EU Commission http://ec.europa.eu/environment/waste/packaging_index.htm (accessed 28 Feb 2007)

2D.3.1 Goals and scope of AKST

The goal of food sufficiency was successfully met in North America and Western Europe through focusing AKST on the productivity of land, labour and farmer profits. This goal was not achieved to the same extent in Eastern Europe largely due to the socio-economic and political system, a centralized approach to AKST, restructuring and instability. However, the food systems developed in NAE do not provide full food security within all parts of NAE itself due to societal circumstances. They also rely for to a large extent on resources outside NAE, which has not only resulted in inequity but also hinders meeting the IAASTD goals outside NAE. Negative consequences of this development of AKST and agriculture in NAE were great environmental, animal welfare and social costs, which did not remain within the NAE borders. Many of these costs are difficult to quantify and were initially largely ignored. Such negative externalities are increasingly being addressed but impacts can be difficult and sometimes impossible to recover. As discussed in the previous subchapters, NAE AKST attempts to assist in reducing hunger outside NAE were only partially successful.

To meet the goals addressed by the IAASTD it appears advisable to define the scope of AKST in very broad terms. AKST needs to embrace whole *food systems*, focusing on and integrating all their dimensions (social, economic and ecological), levels (including e.g. inputs such as financing, agriculture, processing, transportation, trade, consumption, waste, public goods and costs) and scales (from local to global). AKST has to provide knowledge of the kinds of food systems which would help to meet the goals and how such food systems could be achieved. AKST has to cope with the societal contexts and preconditions, it should integrate varied perspectives and needs of their actors, and multiple disciplinary views to strive for diverse systems with synergy among the different dimensions of sustainable development.

2D.3.2 Approaches and tools of AKST

The reduction in integration of the scientific communities and varied voices (especially of the most vulnerable beneficiaries) in the AKST processes after the Second World War contributed to the partial failure of AKST and agriculture in terms of the IAASTD goals. Since the 1970s, the problems caused by these structural changes led to a gradual reversal of approach as more system-orientated approaches, more participation of varied stakeholders in AKST and increased interaction between the agricultural, environmental and social sciences were promoted. This process started in international development research and similar approaches have been increasingly adopted within NAE. Interdisciplinarity seems to be the preferable approach for AKST rather than continuous emergence of new disciplines by unifying old ones. Interdisciplinarity still has a variety of barriers to overcome and requires strong, advancing disciplinary systems-oriented bases. Communication across disciplinary borders seems to be the most crucial barrier to achieve true interdisciplinarity. Organizational structures based on the basic sciences and disciplinary traditions in funding and merit systems create disincentives to interdisciplinarity. Options to improve the situation include education to understand diverse science philosophic approaches, the use of conceptual tools to facilitate the process as well as development of interdisciplinary review systems and publication channels. Transdisciplinarity and participation (2D.1.3, Table 2D, 3, Text box 2D, 3) towards governance by the relevant agri-food system actors (including those relating to rural livelihoods, environment and the poor) require reconsideration of employees' reward systems. The progressive move from the linear technology generation and transfer to farmers, towards *knowledge networks* crossing horizontal and vertical borders implies collective learning (societal learning) with repeated feed-back loops, for co-innovation processes that can successfully meet the goals of the IAASTD in dynamic and complex environments.

2D.3.3 Structures and funding of AKST in NAE

The degree in integration of education, research and extension varied among the countries of North America, Western and Eastern Europe. The integrated model applied in the US was particularly successful, especially in contrast to the centralised approach applied in much of Eastern Europe in the past. Decentralized decision-making seems to foster diversity, adaptation to local circumstances and innovation and is thus likely to help meeting the goals of the IAASTD.

The proportion of private funding of AKST in NAE has increased since the Second World War, a change that influenced the type of agriculture-related research conducted as well as allocation of public funding for research, training and extension. Public funding in AKST-related research tended to stagnate in many parts of NAE. AKST ha focussed increasingly on wealth creation, industrial, high-technology input development and food processing increased as a proportion of total AKST. Health and food safety concerns and consumers' seeking of comfort and pleasure have been increasingly addressed within the industrial framework. Distributional issues have received less attention.

In recent decades recognition of environmental and social problems has gradually caused a shift away from this focus on wealth creation to other public goods. However, the move towards diverting more funding to universities at the expense of more applied AKST institutions further emphasized the role of basic sciences and increased the gap between basic and applied research and between research and non-academic stakeholders (especially rural ones). This development needs to be reversed to help meet the goals of the IAASTD.

Throughout much of NAE competition and a short-term outlook were increasingly built into the public funding system for AKST on different levels, a change that continues to the present day. From the point of view of the funding agencies this change in approach was meant to ensure quality, transparency, efficiency and value for money for tax payers. Although this approach has favoured certain aspects of scientific performance and international collaboration, it has been suggested that is has also resulted in extreme competitiveness, suboptimal use of public resources (including increased bureaucracy), loss of scientific commitment to public goods and long term goals. These changes hinder the evolution of partnership-based knowledge networks which would help with achieving the development and sustainability goals addressed by the present assessment. Short-term contracts also disadvantage time-demanding integration and favour laboratory research at the expense of more field-based agricultural and sustainability-oriented R&D. The latter trend was supported by the rise of method-orientation over problem-oriented R&D encouraged by competitive grants and a merit system increasingly based on quantification of publication outputs. In the EU the 5th and 6th Framework Programs have in recent years sought to counteract these trends and promote more integrated R&D focussed on public goods, although the focus was different from that of the IAASTD.

2D.3.4 Interaction of NAE AKST with the rest of the world

Initially the contribution of NAE AKST to international research was implemented through technology transfer with considerable success but over time the limits of this approach became apparent with some severe consequences for the achievements of the development and sustainable goals. New ways forward were found through development of integrated approaches but old structures and attitudes continued to cause friction. In recent years NAE AKST has increasingly focussed on applications within the developed world at the expense of applications appropriate for poor rural developing countries.

Part of the expert community believes that the international significance of NAE AKST has declined in the latter half of the period. Others claim that new technology developed by AKST in recent years has been very significant for developing countries although uptake has been uneven. World AKST has further concentrated spatially in NAE and in a few large developing countries. This trend has been fostered by NAE AKST sciences focussing increasingly on basic sciences, high-tech approaches, industrial applications and consumer concerns, by a higher proportion of AKST-relevant R&D being funded by companies as well as by safety restrictions set by donors for use of funds. Spillover of AKST from NAE to developing countries is thus declining. Some see the introduction of regulatory policies such as intellectual property rights, biosafety protocols and trading regimes as further endangering equity between NAE and the rest of the world. Others disagree referring to conventions on availability of germplasm, access and benefit sharing which were introduced alongside intellectual property rights, and that in fact some people in the developing world think of the Cartagena Protocol on Biosafety as a tool to balance some of the perceived inequities.The dependence and adverse ecological impacts of NAE agriculture and food supply on areas outside NAE have also increased. These developments hinder meeting the development and sustainability goals of the present assessment.

2D.3.5 Drivers of NAE AKST in relation to the IAASTD goals

In the period since the Second World War the main direct drivers of NAE AKST in relation to the IAASTD goals were new KST and shifts in paradigms and demand. As a consequence, there was evolution in policies, regulations and markets. KST (incl. AKST) made industrialization and technological development as well as urbanization possible, but was also crucially influenced by these changes. The indirect drivers of NAE AKST were predominantly societal circumstances. In Europe the Second World War resulted in loss of infrastructure and food insecurity but it also promoted industrialization and technological development throughout NAE. The war was followed by a rebuilding period characterized by a faith in technology. The establishment of larger economic and/or political structures in Europe (the EU and its predecessors) has had a marked effect on AKST in ever larger parts of Europe (as membership increases). In Eastern Europe the drastic societal restructuring in the late 1980s and the 1990s increased the risks of poverty, hunger and malnutrition for parts of the population in many of the affected countries. However, opening to the West also provided opportunities for AKST (e.g. in increasing environmental sustainability) even though positive impacts may take time to take effects. The wealth differences in the developed and developing world, intensified by wars and conflicts outside NAE, directly hindered meeting the goals: Lower production costs in developing countries resulted in cheap resources for processing in NAE, thus further enhancing inequity between NAE and developing countries. Policies and search for short-term returns for AKST in NAE, together with development of IPR protection, were the main drivers behind increases in privatization and introduction of increased competition to AKST management. This again created barriers for meeting the goals. Policy-makers and governments will have a key role in developing measures that help meeting the goals. To help meet the development and sustainability goals of the present assessment a stronger focus on a wider range of public goods will be required. This may entail a paradigm shift towards a higher proportion of publicly-funded AKST. This paradigm shift within AKST should involve more comprehensive adoption, application and institutionalization of horizontal (sciences), vertical (actors) and contextual (societal and ecological circumstances) integration as well as collective learning (societal learning) within NAE and in the international context.

References

Accenture. 2007. UK Levy Boards: Research to Underpin the Fresh Start Review. 16 pp. http://www.defra.gov.uk/farm/policy/levy-bodies/freshstart/pdf/research-report.pdf

Ackoff RL 1983 The future of operational research is past. J. Operational Res. Soc. 30, 93-104.

ACRE. 2006. Managing the Footprint of Agriculture:Towards a Comparative Assessment of Risks and Benefits for Novel Agricultural Systems: Report of the ACRE Sub-group on Wider Issues Raised by the Farm-Scale Evaluations of Herbicide Tolerant GM Crops (Consultation Draft). Advisory Committee on Releases to the Environment. London. http://www.defra.gov.uk/environment/acre/ fsewiderissues/acre-fse-060317draft.pdf.

Alrøe HF and Kristensen ES 1998 Sustainability and organic farming. In: Research Methodologies in Organic Farming. Eds. R Zanoli and R Krell. FAO, Regional Office for Europe, No. 58 (in preparation).

Alston, J. M. 2002. "Spillovers." Australian Journal of Agricultural and Resource Economics 46: 315-346.

Alston, J.M., M.C. Marra, P.G. Pardey and T. J. Wyatt. 2000. Research returns redux: a meta-analysis of the returns to agricultural R&D. The Australian Journal of Agricultural and Resource Economics 44 (2):185.

Alston, J.M., G.W. Norton and P.G. Pardey. 1995. Science under scarcity: Principles and Practice of Agricultural Research Evaluation and Priority Setting. Ithaca NY: Cornell University Press.

Alston, J.M., P.G. Pardey and V.H. Smith. 1998. Financing agricultural R&D in rich countries: What's happening and why? The Australian Journal of Agricultural and Research Economics 42(1): 51-82.

Anon. 2004. Statistics of the Institute of Rural Sciences of the University of Wales. Europe: The Development of Organic Farming between 1984 and 2004. http://www.organic.aber.ac.uk/statistics/europe05.html

Apostel, L., G. Berger, A. Briigs, G. Michaud., (Eds.) 1972. *Interdisciplinarity. Problems of Teaching and Research in Universities*. Paris, Organization for Economic Co-operation and Development.

Ashley, C. and S. Maxwell. 2001. Rethinking Rural Development. Development Policy Review 19(4):395-425.

Balmford et al., 2005. Sparing landd for nature: exploring the potential impact of changes in agricultural yield on the area needed for crop production. Global Change Biology 11:1594-1605.

Balvanera, P., Daily, G.C., Ehrlich, P.R., Ricketts, T.H., Bailey, S.A. 2001. Conserving biodiversity and ecosystem services. Science 291:2047-.

BANR. 2002. Publicly Funded Agricultural Research and the Changing Structure of US Agriculture Board on Agriculture and Natural Resources (BANR). Committee to Review the Role of Publicly Funded Agricultural Research on the Structure of US Agriculture, Board on Agriculture and Natural Resources, National Research Council. http://darwin.nap.edu/execsumm/0309076161.html

Barney, G. O. 1981. The Global 2000 Report to the President : Entering the Twenty-first Century. A report by the Council on Environmental Quality and the Department of State, Washington DC.

Bauer, M. W. and G. Gaskell (eds.). 2002. *Biotechnology: The Making of a Global Controversy*. Cambridge University Press.

Bawden RJ 1991 Systems thinking and practice in agriculture. J. Dairy Sci. 74, 2362-2373.

Bawden RJ, Ison RL, Macadam RD, Packham RC and Valentine I 1985 A research paradigm for systems agriculture. In Agricultural systems research for developing countries. Ed. JV Remenye. pp. 31-42. Canberra.

BBSRC. 2004. Review of BBSRC-funded research relevant to crop science. Biotechnology and Biology Research Council, Swindon, UK, 56 pp, http://www.bbsrc.ac.uk/about/pub/reports/crop_sci_review12_05_04.pdf

Becker, T. 2000. Participatory research in the CGIAR. A discussion paper prepared for the NGO-workshop Food for All – Farmer First in Research, accompanying the GFAR in Dresden.

Beckett, M. 2004. Secretary of State Margaret Beckett's statement on GM policy. Department for Environment, Food and Rural Affairs, 9 March 2004, London, UK, http://www.defra.gov.uk/corporate/ministers/statements/mb040309.htm.

Beintema et al. Agricultural knowledge, science and technology: investment and economic returns. IAASTD Global Assessment ….. (in prep).

Bentley, J., 1994. Facts, fantasies and failures of Farmer Participatory Research. Agriculture and Human Values, 11(243), 140-150.

Bertalanffy L von 1973 General system theory. Foundations, developments, applications. George Braziller, Inc., N.Y. 311 p.

Björklund, S. 1999. Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services: an example from Sweden. Ecological Economics 29: 269-291.

Björklund, S. 2004. Ecosystem services in an agricultural context.p. 21-24. In Agerlid, G. (ed.) Ecosystem services in European agriculture – theory and practice. Journal of the Royal Swedish Academy of Agriculture and Forestry 143:1.

Bohan, D., C. Boffey, et al. (2005). "Effects on weed and invertebrate abundance and diversity of herbicide management in genetically modified herbicide-tolerant winter-sown oilseed rape." Proceedings of the Royal Society B 272(1562): 463-474.

Boserup, E. 1965. The Conditions of Agricultural Growth: The Economics of Agrarian Change under population Pressure. Allen and Unwin, London.

Bouma et al., 2002. Ecological Economics

Bretschart, A. A. 2005. Scientific excellence – foundation for USDA policy. Abstracts of the XIX EURAGRI Members Conference 2005, York, UK, http://euragri.csl.gov.uk/

Bruun, H., J. Hukkinen, K. Huutoniemi, and J.T. Klein. 2005. Promoting Interdisciplinary Research. The case of the Academy of Finland. Publications of the Academy of Finland 8/05. http://www.aka.fi/modules/upndown/download_file.asp?id=739D547AF6994623AC202B859A1A94DC&tabletarget=data_1&pid=E12080C439CB48A191E80295F382194F&layout=aka_fi_sisa

Buhler, W., S. Morse, E. Arthur, S. Bolton and J. Mann (2002). Science, agriculture and Research, a compromised participation? Earthscan Publications Ltd., London. http://books.google.com/books?ie=UTF-8&id=Dy3WYKkq7LMC&dq=application+of+science+in+agriculture&psp=wp&pg=PP5&printsec=4&lpg=PP5&sig=sld0CC85-sg0D1el7LpNAKVXzYQ

Buller, H. and C. Morris (2003). "Farm animal welfare: a new repertoire of nature-society relations or modernism re-embedded?" Sociologia Ruralis **43**(3): 216-237.

Bunge M 1985 Treatise on basic philosophy vol. 7, Epistemology & Methodology III: Philosophy of science and technology Part II. Reidel, Dordrecht. 341 p.

Busch, L., J.L.Silver, W.B.Lacy, C.S.Perry, M.Lancelle, and S.Deo. 1984. The Relationship of Public Agricultural R&D to Selected Changes in the Farm Sector. Report to the National Science Foundation. Lexington, Ky.: Department of Sociology, Agricultural Experiment Station, College of Agriculture, University of Kentucky.

Busch, L. 2005. Commentary on “Ever since Hightower: The politics of agricultural research activism in the molecular age”. *Agriculture and Human Values* 22: 285-288.

Buttel, F. 1986. Biotechnology and Agricultural Research Policy: Emergent Research Issues. In: New Directions for Agriculture and Agricultural Research. K. Dahlberg, ed. Totowa, N.J.: Rowmand & Allanheld, pp. 312-347.

Buttel, F. H. 2005. Ever since Hightower: The politics of agricultural research activism in the molecular age. *Agriculture and Human Values* 22, 275-283.

CGIAR. 2005. CGIAR Annual Report 2004 - Innovations in Agricultural Research. CGIAR Secretariat Publications:Annual Reports.

CGIAR, 2006. History of the CGIAR. http://www.cgiar.org/who/history/index.html

CGIAR Science Council. 2005a. *Science for Agricultural Development: Changing Contexts, New Opportunities*, Rome, Italy, Science Council Secretariat.

CGIAR Science Council. 2005b. Science Council Brief.

Chataway, J., Tait, J. and Wield, D. (2004) Understanding company R&D strategies in agro-biotechnology: Trajectories and Blindspots. Research Policy, 33/6-7, 1041-1057.

Checkland PB 1981 Systems thinking, systems practice. John Wiley & Sons, N.Y. 330 p.

Checkland PB 1988 Images of systems and the systems image: presidential address to ISGSR. J. Appl. Syst. Anal. 15, 37.

Chesbrough, H. W. 2003. Open Innovation. The New Imperative for Creating and Profiting from Technology. Boston, MA, Harvard Business School Press.

CIPR. 2002. Commission on Intellectual Property Rights. London, UK.

Constantine, J., J.M. Alston and V.H. Smith, 1994. Economic impacts of California’s one variety cotton law. Journal of Political Economy 102(5):66-89.

Conway, G. 1997. The Doubly Green Revolution, Penguin Books , London.

Cooke, P. and K. Morgan, Eds. (1998). *The Associational Economy. Firms, Regions, and Innovation*. Oxford, Oxford University Press.

Costanza et al., 1997. The value of the world’s ecosystem services and natural capital. Nature 387:253-260.

Daily, G. (ed.) 1997. Nature’s Services. Societal Dependence on Natural Ecosystems. Island Press, Washington DC.

Danford, W. H. 2006. Funding basic agricultural research. Science 314, 223.

DeFries, R. and L. Bounoua. 2004. Consequences of land use change for ecosystem services: A future unlike the past. GeoJournal 61:345-351.

Deutsch, L. 2004. Global Trade, Food Production and Ecosystem Support: Making the interactions visible. Doctoral thesis, Department of Systems Ecology. Stockholm, Stockholm University.

De Wit, C.T. 1986. Introduction. In: Van Keulen, H. and J. Wolf (eds.) Modelling of agricultural production: weather, soils and crops. pp. 3-10. Simulation Monographs, Pudoc, Wageningen.

Dik, A. J. 2004. Bulletin OILB/SROP 27 (8) 421-423. Proceedings of a Meeting of the IOBC/WPRS Working Groups 'Management of Plant Diseases and Arthropod Pests by BCAs and their integration in Agricultural Systems', Trentino, Italy, 9-13 June 2004.

Douglass, G.K. 1984. The meanings of agricultural sustainability. p.1-29 In G.K. Douglass (ed.) Agricultural sustainability in a changing world order.

Ellis, F. and S. Biggs. 2001. Evolving themes in Rural development in 1950s-2000s. Development Policy Review 19:437-448.

El Titi, A. 1992. Integrated farming: an ecological farming approach in European agriculture. Outlook on Agriculture 21 (1), 33-39.

ETAN. 2000. Science Policies in the European Union: Promoting excellence through mainstreaming gender equality. European Technology Assessment Network, European Commission, Brussels, http://cordis.europa.eu/improving/women/documents.htm

EURAGRI. 2005. Anticipating the future: Knowledge based policy for European Agriculture. XIX Members Conference of the European Agricultural Research Initiative, York, UK, http://euragri.csl.gov.uk/aims.cfm

European Commission. 2006. She Figures 2006. Women and Science. Statistics and Indicators. Directorate General for Research, Burssels. http://ec.europa.eu/research/science-society/women/wssi/publications_en.html

European Communities Statistical Office (1968) The Common Market 10 years on. Brussels 1968

Evenson, R.E. 1983. Intellectual Property Rights and Agribusiness Research and Development: Implications for the Public Agricultural Research System. American Journal of Agricultural Economics 65 (1983): 967-975.

Falcon, W.P. and Naylor, R.L. 2005. Rethinking food security for the twenty-first century. Amer. J. Agr. Econ. 87(5): 1113-1127.

Fennel, R. 1997. The Common Agricultural Policy Continuity and Change Clarendon Press Oxford.

FEMtech. 2006. Facts and Figures. Austrian Research Promotion Agency_ http://www.femtech.at/index.php?id=467 (accessed 13 Feb 2007)

Fuglie, K. et al. 1996. Agricultural Research and Development: Public and Private Investments Under Alternative Markets and Institutions. US Department of Agriculture, ERS, Agricultural Information Report (735).

Galison, P. and B. Hevly (1992). *Big Science. The Growth of Large-Scale Research*. Stanford, CA, Stanford University Press.

Gibbons, M., C. Limoges, H. Nowotny, S. Schwartzman, P. Scott and M. Trow. 1994. The New Production of Knowledge. The Dynamics of Science and Research in Contemporary Societies. SAGE Publications, London, UK.

Green, R.E., S.J.Cornell, J.P.W. Scharlemann, and A. Balmford. 2005. Farming and the fate of wild nature. Science 307:550-555

Griliches, Z. 1958. Research Costs and Social Returns: Hybrid Corn and Related Innovations. J. Pol. Econ. 65: 419-465.

Griliches, Z. 1979. Issues in Assessing the Contribution of Research and Development to Productivity Growth. Bell Journal of Economics 10: 92-116

Groot, J. C. J., M. Stuiver and L. Brussaard. 2004. Land use systems in grassland dominated regions. In: Luscher, A.; Jeangros, B.; Kessler, W.; Huguenin, O.; Lobsiger, M.; Millar, N.; Suter, D. (eds). Proceedings of the 20th General Meeting of the European Grassland Federation, Luzern, Switzerland, 21-24 June 2004, 1202-1204

Grove-White, R., P. Macnaghten and B. Wynne. 2000. Wising Up. The Public and New Technologies. Report, 44 pp, Lancaster University, http://csec.lancs.ac.uk/docs/wising_upmacnaghten.pdf.

Harris, S.F., 1982. Agricultural trade and its international trade policy context. In: Agriculture in the Australian Economy. (D.B. Williams, Ed.) Sydney University Press, Sydney.

Hawes, C., A. J. Haughton, et al. (2003). "Responses of plants and invertebrate trophic groups to contrasting herbicide regimes in the Farm Scale Evaluations of genetically modified herbicide-tolerant crops." Philosophical Transactions of the Royal Society of London - Series B: Biological Sciences 358: 1899-1913.

Hayami, Y. and V.W. Ruttan. 1971. Agricultural Development: An International Perspective. Baltimore, Md.The Johns Hopkins University Press.

Heard, M. S., C. Hawes, et al. 2003a. "Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops. I. Effects on abundance and diversity." Philosophical Transactions of the Royal Society of London - Series B: Biological Sciences 358: 1819-1832.

Heard, M. S., C. Hawes, et al. 2003b. "Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops. II. Effects on individual species." Philosophical Transactions of the Royal Society of London - Series B: Biological Sciences 358: 1833-1846.

Heemskerk, M., K. Wilson.and M. Pavao-Zuckerman. 2003. Conceptual models as tools for communication across disciplines. Conservation Ecology 7(3):8. [online]

Huffman, W.E. 1996. Labor Markets, Human Capital, and the Human Agent's Share of Production, In: J.A. Antle and D.A. Sumner (eds.) The Economics of Agriculture: Papers in Honor of D. Gale Johnson, vol. 2. , pp. 55-79. Chicago: The University of Chicago Press.

Huffman, W.E. 1998a. Modernizing agriculture: A continuing process, *Daedalus* (fall issue)

Huffman, W.E. 1998b. Education and Agriculture. In: G. Rausser and B. Gardner (eds.) Handbook of Agricultural Economics. Amsterdam, Netherlands: North Holland.

Huffman, W.E. 2005. Developments in the Organization and Finance of the Public Agricultural Research in the U. S. 1988-1999. Department of Economics. Working Papers Series, December 2005. Iowa State University. Ames, Iowa.

Huffman, W.E. and R.E. Evenson. 1993. Science for Agriculture: A Long Term Perspective. Ames IA, Iowa State University Press.

Huffman, W.E., and R.E.Evenson. 2001. Structural and productivity change in US agriculture, 1950–1982. Agricultural Economics 24(2):127–147.

Huffman, W.E. and R.E. Just. 1994. Funding, Structure and Management of Public Agricultural Research in U. S.. Amer. J. Agric. Econ. 76:744-759.

Huffman, W.E. and R. E. Just. 1998. The Organization of Agricultural Research in Western Developed Countries. Department of Economics, Iowa State University, Iowa, staff paper no. 304.

Huffman, W.E. and R.E. Just. 1999. Benefits and Beneficiaries of Alternative Funding Mechanisms. Rev. Agr. Econ. 19: 2-18.

Huffman, W.E. and R. E. Just. 2000. Setting Efficient Incentives for Agricultural Research: Lessons from Principal-Agent Theory. Amer. J. Agr. Econ. 82: 828-841.

Humphries, S., Gonzalez, J., Jimenez, J. and Sierra, F., 2000. Searching for sustainable land use practice in Honduras: Lessons from a program of participatory research with hillside farmers. Overseas Development Institute. Agricultural Research and Extension Network Paper No. 104, July.

Hunger Project. 2005. The Hunger Project website. Available at:http://www.thp.org.

ICI. 1978. Jealott’s Hill Fifty years of Agricultural Research 1928 – 1978. Imperial Chemical Industries Plant Protection Division, ISBN 0 901747 01 7.

IOBC. 1999. Integrated Production. Principles and Technical Guidelines. 2nd edition. Edited by E.F. Boller, A. El Titi, J.P. Gendrier, J. Avilla, E. Jörg & C.Malavolta. IOBC/WPRS Bulletin 22(4), 37 pp.

Ingram, J. and C. Morris. 2007. The knowledge challenge within the transition towards sustainable soil management: An analysis of agricultural advisors in England. Land Use Policy 24 (1), 100-117

James, P.G. 1971. Agricultural Policy in Wealthy Countries. Angus & Robertson, Sydney.

Jantsch E 1975 Design for evolution. George Braziller, N.Y.

Johansson, S. 2005. The Swedish foodprint – An Agroecological Study of Food Consumption. Doctoral dissertation. Acta Universitatis Agriculturae Sueciae 2005:56. SLU Service/Repro, Uppsala.

Jorgenson, D.W., F. M. Gollop and B. M. Fraumeni. 1987. Productivity and US Economic Growth. Cambridge, Mass., Harvard University Press.

Jorgenson, D.W. and F. M. Gollop. 1992. Productivity Growth in US Agriculture: A Postwar Perspective. American Journal of Agricultural Economics 74:745-750.

Just, R.E. and Huffman, W.E. 1992. Economic Principles and Incentives: Structure, Management, and Funding of Agricultural Research in U. S.. Amer. J. Agr. Econ. 74:1101-1108.

Labarthe, P. 2006. Changing European farming systems for a better future: new visions for rural areas. 7th European IFSA Symposium on New Visions for Rural Areas, Wageningen, NL, 7-11 May 2006, p. 330-334..

Lambert, D. M., P. Sullivan, R. Claassen and L. Foreman (2007). "Profiles of US farm households adopting conservation-compatible practices." Land Use Policy 24: 72-88.

Laszlo, E. and Laszlo, A. 1997. The contribution of the systems sciences to the humanities. Syst. Res. Behav. Sci. 14, 5-19.

Lele, S. and R.B. Norgaard. 2005. Practicing interdisciplinarity. Bio Science 55:967-975.

Kahiluoto, H., Berg, P., Granstedt, A., Fischer, H., Thomsson, O. (eds.) 2006. Localisation and recycling in Baltic Rural Food Systems –Interdisciplinary Synthesis. Baltic Ecological Recycling Agriculture and Society (BERAS) Nr. 7. Centre for Sustainable Agriculture (CUL). Swedish University of Agricultural Sciences.

Klein, J.T. 1996. Crossing Boundaries. Knowledge, Disciplinarities, and Interdisciplinarities. University Press of Virginia, Charlottesville, VA, and London, UK.

MA. 2005. Millennium Ecosystem Assessment Synthesis Report. A Report of the Millennium Ecosystem Assessment.

MacDonald, D., J. R. Crabtree, G. Wiesinger, T. Dax, N. Stamou, P. Fleury, J. G. Lapita and A. Gibon. 2000. Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. *Journal of Environmental Management* **59**, 47-69.

Mann, C. 1997. Reseeding the green revolution. Science 277:1038-1043.

Mann, C. 1997. Reseeding the green revolution. Science 277:1038-1043.

Mansilla, V.B. and Gardner, H. 2003. Assessing interdisciplinary work at the frontier. An empirical exploration of 'symptoms of quality'. Interdisciplines. Rethinking interdisciplinarity. http://www.interdisciplines.org/interdisciplinarity/papers/6/7

Masefield, G.B. 1972. A History of the Colonial Agricultural Service. Clarendon Press, Oxford.

Miettinen, R. (2002). *National Innovation Systems. Scientific Concept or Political Rhetoric*. Edita, Helsinki.

Miller, R.J., P. Sorokin, Y.F. Lachuga, S. Chernakov and A.D. Goecker. 2000. A comparison of Agricultural Higher Education in Russia and the United States. J. Nat. Resour. Life Sci. Educ. 29:68-77.

Moore, N.W. (1987) *The Bird of Time*. Cambridge: Cambridge University Press.

Morris, C. (2006). "Negotiating the boundary between state-led and farmer approaches to knowing nature: An analysis of UK agri-environment schemes." Geoforum **37**(1): 113-127.

Morris, S. H. (2007). EU biotech crop regulations and environmental risk: a case of the emperor's new clothes? Trends in Biotechnology **25**(1): 2-6.

Morris, C. and M. Winter (1999). "Integrated farming systems: the third way for European agriculture." Land Use Policy **16**: 193-205.

Nickel, J.L. 1997. A global agricultural research system for the 21st century. In: C. Bontefriedheim and K. Sheridan (eds.) The Globalization of Science: The Place of Agricultural Research. pp. 139-155. ISNAR, The Hague.

Nipp, T. 2004. Agrosecurity: the role of the agricultural experiment stations. Journal of Food Science 69, CRH50-CRH54

OECD. 1967. Agricultural Policies in 1966. Organisation for Economic Co-operation and Development, Paris.

OECD 1999. Summary and evaluation of main developments and changes in organizational forms of and approaches by the AKS in OECD member countries. Directorate for Food, Agriculture and Fisheries, Committee for Agriculture. AGR/CA/AKS(00)4 40 pp.

OECD. 2005a. Governance of Innovation Systems Vol 1. Synthesis Report. http://www.oecd.org/document/25/0,2340,en_2649_37417_35175257_1_1_1_37417,00.html

OECD. 2005b. Governance of Innovation Systems Vol. 2: Case Studies in Innovation Policy.

OECD. 2005c. Governance of Innovation Systems Vol.3. Case studies in Cross-Sectoral Policy. http://www.oecd.org/document/12/0,2340,en_2649_37417_35791756_1_1_1_37417,00.html

Office of Technology Assessments. 1992. New Technological Era for American Agriculture. Washington, D.C. US Government Printing Office.

Olmstead, A.L.and P. Rhodes. 1994. The agricultural mechanization controversy of the interwar years. Agricultural history 68:3.

OSI. 2006. Science Review of the Department for Environment, Food and Rural Affairs. London, UK Office of Science and Innovation**:** 88 pp., http://www.dti.gov.uk/science/science-in-govt/works/science-reviews/review/defra/page24808.html.

Ostrom, M. and D. Jackson-Smith. 2005. Defining a purpose: Diverse farm constituencies and publicly funded agricultural research and extension. Journal of Sustainable Agriculture 27, 57-76.

Odum HT 1983 Systems ecology. Wiley, N.Y. 644 p.

Odum HT 1988 Self organization, transformity, and information. Science 242, 1132-1139.

Pardey, P.G., and N. M. Beintema. 2001. Slow magic: Agricultural R&D a century after Mendel. IFPRI food policy report. International Food Policy Research Institute. Washington, DC

Pidgeon, N. F., W. Poortinga, et al. 2005. "Using surveys in public participation processes for risk decision making: the case of the 2003 British GM Nation public debate." Risk Analysis **25**(2): 467-479.

Pretty, J. 1995. Regenerating Agriculture: Policies and Practice for Self-Reliance. London. Earthscan Publications Ltd. and Washington DC. National Academy Press.

Pretty, J.N., A.D. Noble, D. Bossio, J. Dixon, R.E. Hine, F.W.T. penning de Vries and J.L.L. Morrison. 2006. Resource-conserving agriculture increases yields in developing countries. Environmental Science and Technology.

RCEP. 1989. Thirteenth Report: the Release of Genetically Engineered Organisms to the Environment. Royal Commission on Environmental Pollution, London, HMSO.

Read, N., Quinn, J. J. and A. Webster. 1988. Commercialisation as a policy mechanism in UK agricultural research, development and extension. Agricultural Systems 26, 77-87.

Rhodes, F. H. T. 2001. The Creation of the Future. The Role of the American University. Ithaca and London, Cornell University Press.

Romig, D.E., et al., 1995. How farmers assess soil health and soil quality. Journal of Soil and Water Conservation 50, 229–236.

Romig, D. E., M. J. Garlynd and R. F. Harris. 1996. Farmer-Based Assessment of Soil Quality: A Soil Health Scorecard. In: Methods for Assessing Soil Quality, SSSA Special Publication 49, Soil Science Society of America. Madison, http://www.cias.wisc.edu/wicst/pubs/farmer_based.htm

Roy, D. B., D. A. Bohan, et al. (2003). "Invertebrate and vegetation of field margins adjacent to crops subject to contrasting herbicide regimes in the Farm Scale Evaluations of genetically modified herbicide-tolerant crops." Philosophical Transactions of the Royal Society of London - Series B: Biological Sciences 358: 1879-1898.

Roy, S. 1990. Agriculture and technology in Developing Countries: India and Nigeria, Sage Publications, India, New Delhi.

Rubenstein, K.D., P.W. Heisey, C. Klotz-Ingram and G.B. Frisvold. 2001. Competitive Grants and the Funding of Agricultural Research in the U. S.. Review of Agricultural Economics 25(2): 352-368.

Rubenstein, K. D. and P. W. Heisey. 2005. "Can technology transfer help public-sector researchers do more with less? The case of the USDA's Agricultural Research Service." AgBioForum 8(2/3): 134-142.

Ruttan, V.W. 1982. Agricultural Research Policy. Minneapolis MN: University of Minneapolis Press.

Rydberg, T. 2004. Evaluation of ecosystem services – a theoretical approach. p. 25-28. In Agerlid, G. (ed.) Ecosystem services in European agriculture – theory and practice. Journal of the Royal Swedish Academy of Agriculture and Forestry 143:1.

Sabatier, P.A. and Jenkins Smith, H.C. 1993. Policy Change and Learning: an Advocacy Coalition Approach. Colorado: Westview Press

Schienstock, G., Ed. 2004. Embracing the Knowledge Economy. The Dynamic Transformation of the Finnish Innovation System. New horizons in the economics of innovation. Cheltenham, UK ; Northampton, MA, Edward Elgar.

Schultz, T.W. 1953. The Economic Organization of Agriculture. New York NY: McGraw Hill.

Schultz, T.W. 1971. The allocation of resources to research. In: W.L. Fischel (ed.) Resource Allocation in Agricultural Research. pp. 90-120. Minneapolis, University of Minnesota Press.

Schultz, T.W. 1980. The Entrepreneurial Function in Agricultural Research. University of Chicago, Dept. of Economics, Agricultural Economics Paper No. 80:29.

Schultz, T.W. 1982. Knowledge Activities of Universities. A critical view. University of Chicago, Dept. of Economics, Human Capital Paper No. 82:1.

Schultz, T.W. 1983. An Economist's Assessment of Agricultural Research. University of Chicago, Dept. of Economics, Agricultural Economics Paper No. 83:28.

Schultz, T.W. 1985. Agricultural Research, Canada and Beyond. In: K.K. Klein and W.H. Furtan (eds.). Econ. Agr. Res. In Canada. pp. 11-20.

Smil, V. 1998. Nature's services, human follies. Population and Development Review 24(3):613-623.

Smil, V. 2000. Phosphorus in the environment: natural flows and human interferences. Annu. Rev. Energy Environ. 25: 53-88.

Slaughter, S. and L. L. Leslie. 1997. Academic Capitalism. Politics, Policies, and the Entrepreneurial University. Baltimore, Johns Hopkins University Press.

Spedding, C. R. W. 1979. An introduction to agricultural systems. Elsevier Appl. Sci. Publ., London. 69 p.

Stephens, W. and T. Hess. 1999. Systems approaches to water management research. Agricultural Water Management 40: 3-13.

Stokes, D. 1997. *Pasteur's Quadrant. Basic Science and Technical Innovation*. Washington D.C., Brookings Institution Press.

Suarez-Seone, S., P. E. Osborne and J. Baudry. 2002. Responses of birds of different biogeographic origins and habitat requirements to agricultural land abandonment in northern Spain. *Biological Conservation* **105**, 333-344.

Sumberg, J. and Okali, C., 1997. Farmer's experiments: Creating local knowledge. Lynne Rienner, London.

Sumberg, J., C. Okali and D. Reece. 2003. Agricultural research in the face of diversity, local knowledge and the participation imperative: theoretical considerations. Agricultural Systems 76, 739-753.

Sutherland, J.A., S.B. Mathema, T.B. Thapa and S.B. Pandey. 2004. Encouragement of effective research and development partnerships through a process of competitive funding in Nepal. Uganda Journal of Agricultural Sciences 9: 150-156.

Suvedi, M., M. Knight Lapinski and S. Campo. 2000. Farmers' Perspectives of Michigan State University Extension: Trends and Lessons from 1996 and 1999. Journal of Extension 38 (1)

Tait, J. and C. Chataway,. 2006. Risk and Uncertainty in Genetically Modified Crop Development: the Industry Perspective. *Environment and Planning – C.* (in press)

Tait, J., J. Chataway and D. Wield. 2000. Final Report, PITA Project. www.technology.open.ac.uk/cts/projects.htm#biotechnology

Tait, J., J. Chataway and D. Wield. 2006. Governance, Policy and Industry Strategies: Agro-biotechnology and Pharmaceuticals. In eds. G. Dosi and M.Mazzucato, *Knowledge Accumulation and Industry Evolution.* Cambridge University Press, pp 378-401.

Tait, J. and Levidow, L. (1992) Proactive and Reactive Approaches to Risk Regulation: the Case of Biotechnology, *Futures*, April, 1992, pp 219-231.

Thompson, P.B. 1992. The varieties of sustainability. Agriculture and Human Values 9:11-19.

Thompson, P.B. 1997. The varieties of sustainability in livestock farming. p. 5-15 In J.T. Sörensen (ed.) Livestock farming systems – more than food production. Proc. 4th int. symp. on livestock farming systems. EEAP Publ. No. 89.

Tilman, D. 1999. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. Proceedings of the National Academy of Sciences of the U. S. of America. 96(11):5995-6000.

Timmer, D.K., R.C.d. Loë, and R.D. Kreutzwiser. 2007. Source water protection in the Annapolis Valley, Nova Scotia: Lessons for building local capacity. Land Use Policy **24**: p. 187-198.

Tracy, M. 1982. Agriculture in Western Europe - Challenge and Response 1880 – 1980. Chapter 2. Second Edition, Granada, London, IBSN 0 246 11446

Tripp, R. 2001. Agricultural Technology Policy for Rural Development. Development Policy Review 19(4):479-489.

Ulrich, A., W.H. Furtan and A. Schmitz. 1986. Public and private returns from joint research: an example from agriculture. Quarterly Journal of Economics 101(10):101-129.

Umali, D.L. and L. Schwartz. 1994. Public and private agricultural extension: Beyond traditional frontiers. World Bank Discussion Paper No. 236. World Bank, Washington, DC.

UN, 2002. Report of the World Summit on Sustainable Development. Johannesburg, South Africa, 2002. United Nations, New York. http://daccessdds.un.org/doc/UNDOC/GEN/N02/636/93/PDF/N0263693.pdf?OpenElement

UN. 2004. A More Secure World: Our Shared Responsibility. United Nations. New York.

UNCTAD/ICTSD. 2001. Intellectual Property Rights and Development. UNCTAD, Geneva.

UNEP (2002) Enhancing civil society engagement in the work of the United Nations environment programme: strategy paper. UNEP/GC.22/INF/13.

Van-Camp, L., B. Bujarrabal, A-.R. Gentile, R.J.A. Jones, L. Montanarella, C. Olazabal and S.-K. Selvaradjou. (eds.) 2004. Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection. EUR 21319 EN/1-6. Office for Official Publications of the European Communities, Luxembourg. http://eusoils.jrc.it/ESDB_Archive/Policies/STSWeb/vol1.pdf

Van Keulen, H. 2006. Historical context of agricultural development. In: Roetter, R.P., H. van Keulen, M. Kuiper, G. Meijerink and J. Verhagen (Eds.), Science for Agriculture and Rural Development in the South. Springer Verlag.

Vandermeer, J. and I. Perfecto. 2005. The future of farming and conservation. Science 308:1257-

Väyrynen, R. 2006. The Speech of the Director of the Academy of Finland. The 60th Anniversary of the Faculty of Social Sciences, Helsinki University.

Visser, L.E. 2001. Development Sociology and the Interaction Between the Social and Natural Sciences. Asian Journal of Agriculture and development 1(2):69-76.

Von Braun, J. 2000. The New Strategic Directions for the International Agricultural Research. Quarterly Journal of International Agriculture 39:233-236.

Walker, J. 2001. Cultivating Sustainable Agriculture. Unilever Magazine 119 (1), 1-12, http://www.unilever.com/Images/2001%20Cultivating%20Sustainable%20Agriculture_tcm13-5312.pdf.

Walter, G., M. Wander and G. Bollero. 1997. A farmer centered approach to developing information for soil resource management: the Illinois Soil Quality Initiative. America Journal of Alternative Agriculture 12 (2), 64–72.

Wander, M. M. and L. E. Drinkwater (2000). "Fostering soil stewardship through soil quality assessment." Applied Soil Ecology **15**: 61–73. “

Way, M. J. and H. F. v. Emden (2000). "Integrated pest management in practice - pathways towards successful application." Crop Protection 19: 81-103.

WCED. 1987. Our common future. World Commission on Environment and Development. Oxford University Press. Oxford.

Wibberley, J. 1995. Cropping intensity and farming systems: integrity and intensity in international perspective. Journal of the Royal Agricultural Society of England 156, 43-55.

Williams, R. (2000) Public Choices and Social Learning: the New Multimedia Technologies in Europe. Information Society, 16(4), 251-62.

Winter, M. (1997). "New Policies and New Skills: Agricultural Change and Technology Transfer." Sociologia Ruralis 37(3): 363-381.

Winter, M., J. Mills, et al. (2001). Knowledge for Sustainable Agriculture, Report for WWF. http://www.wwf.org.uk/filelibrary/pdf/sust_agriculture.pdf: 42 pp.

Wood, D and J.M. Lenne, 2005. ‘Received wisdom’ in agricultural land use policy: 10 years from Rio. Land Use Policy 22:75-93.

World Bank. 2003a. The CGIAR at 31: An Independent Meta-Evaluation of the Consultative Group on International Agricultural Research. Volume 1: Overview Report, Washington, DC, 58pp.

World Bank. 2003. The CGIAR at 31: Celebrating its achievements, facing its challenges. Precis. World Bank Operations Evaluation Department. Spring 2003. Nr. 232. http://lnweb18.worldbank.org/oed/oeddoclib.nsf/DocUNIDViewForJavaSearch/D01D16C0D67B0F3085256D56005AE040/$file/Precis_232_CGIAR.pdf

Yogendra, S. 2004. *The US Food Quality Protection Act – Review of the Dynamics of Pesticide Regulation and Firm Responses.* Innogen Working Paper 11, http://www.innogen.ac.uk/Publications