NAE Chapter 4

Changes in the Organization and Institutions of AKST and Consequences for Development and Sustainability Goals

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Key Messages

1. **Following the Second World War, agricultural knowledge, science and technology (AKST) had a major role in developing agriculture such that food security was achieved 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 solely production-focused AKST in NAE has been associated with positive consequences but also major negative socioeconomic and environmental externalities, not just within but beyond the NAE borders**. These externalities have been increasingly recognized and attempts are being made to address them, e.g. by addressing and quantifying them through research and reducing them through different policy instruments.

3. **AKST approaches integrating different perspectives are increasingly considered to be fruitful 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 different disciplines and stakeholders interacted in development and application of AKST more extensively. The development in such integration has proceeded mainly in approaches (e.g. research programs, research methods, or educational programs) rather than in organizational structures. Integration has not always proceeded smoothly as a number of barriers have been encountered. On the other hand, some erosion of important established disciplinary expertise has recently occurred as public financial resources for AKST had to cover a wider range of disciplines.
- Integration amongst research, education and extension was from the beginning built into American AKST in contrast to AKST in many European countries. Such integration, as well as integration of AKST and KST and of relevant policies and administrative sectors, has to some extent proceeded recently at the governmental level in Western Europe, increasing the potential to effectively enhance interrelated development and sustainability goals.
- Food systems approaches, as an example of integration, have since the 1990s shown great potential as a way for AKST to address more comprehensively development and sustainability goals.

4. **Between 1945 and the mid-1970s there was a period of rapid growth rates in public agricultural research and development expenditures in NAE. The growth rates then declined. The 1990s saw a slight increase but the growth rates stagnated thereafter**

despite the by then much broader scope of agricultural R&D. Even if the share of public agricultural R&D expenditure from the total R&D expenditure declined, agricultural R&D expenditure relative to the value of agricultural output increased more than the corresponding figures for science and technology research in general. The share of public agricultural research funds given to universities increased considerably from the 1970s onwards in parts of NAE, leading to a shift towards basic research. The economic returns of investments into agricultural R&D have been high with no evidence for a decline, thus offering an argument for ensuring the public funding to meet development and sustainability goals.

5. **The proportion of private funding of AKST in North America and Western Europe has increased since the Second World War, a change that influenced the type of agriculture-related research conducted as well as the allocation of public funding for research, training and extension. Thus the focus of NAE AKST shifted more towards market-driven goals and away from public goods.**

6. **There have been efforts to streamline public agricultural research in the last quarter of the 20th century in some parts of NAE, which had positive as well as negative impacts on AKST.** 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). Where rationalization of facilities took place in response to changes in priorities and scientific methods and to take advantage of new economies of size and scope, this has been beneficial. However, where the aim has been solely to reduce costs, this has also contributed to a fragmentation and weakening of the disciplinary research base and to loss of crucial scientific expertise and facilities.

7. NAE AKST had a major direct and indirect role in the development of the world's agro-food systems. It contributed to successfully reducing hunger in some regions beyond NAE, but had also adverse ecological and socioeconomic effects. In some areas the technology transfer approach was far from successful.

- Agricultural R&D has become increasingly spatially concentrated, increasing inequity. OECD countries and transition economies use most of the resources. This was contributed to by the increase in private funding in NAE. Spending on international R&D (CGIAR) grew in the 1970's but subsequently real spending started to stagnate and decline while the share of restricted funds increased. Expenditures have increased again since 2001 but only represent 1.5% of the global public sector investments in agricultural R&D and 0.9% of all public and private agricultural R&D spending.

- Factors that increasingly limit spillovers 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.

- Indirect effects of NAE AKST on other areas of the world - through changes in agriculture, diet and food systems in NAE - have increased.

8. **The main drivers of NAE AKST in relation to development and sustainability goals were advancements in KST and changes in societal circumstances and interlinked shifts in paradigms. Societal demand, markets and policies (and consequently AKS) evolved under the influence of these developments.**

- Throughout NAE, AKST made a higher degree of industrialization and technological development as well as urbanization possible, but were also crucially affected by these changes. Following the Second World War there was a strong focus in Europe on increasing food supply to ensure food sufficiency and one characteristic of the rebuilding period was a faith in technology throughout NAE. This led to the narrow focus of AKST during this time and further to the adverse environmental and social impacts, which started to gain attention from the 1960/70's onwards.
- In North America and Western Europe in the 1970s, the food crisis had been largely solved, a shift had occurred towards increasing economic liberalization and agriculture by then played a less significant role in the economy. As a result AKST in this region experienced budget-cuts. Since the 1990's policies increasingly took into account the multiple interdependent roles of agriculture. Thus AKST started to cover more comprehensively issues relevant to development and sustainability goals.
- In Central and Eastern Europe, the societal restructuring in the late 1980's and 1990's had a dramatic effect on AKST. At the start of the 21st century the fulfillment of the accessional requirements became a main driver of AKST in the countries which joined the EU during this time.
- The wealth differences between NAE and the developing world as well as conflicts outside NAE have contributed to the continued inequity in AKST between NAE and other parts of the world.

4.1 Lessons Learned: A Synthesis

Paradigm shifts seem to have been major drivers for the changes that have taken place in NAE AKST after the Second World War. The main lesson learned, based on the changes in organization and institutions of AKST in NAE and their consequences, thus is that the dominant paradigms can substantially influence meeting development and sustainability goals of reduced hunger and poverty, improved nutrition and human health, enhanced rural livelihoods and equity, environmental sustainability and sustainable economic development. Institutional and organizational changes in AKST seem to be important factors in helping to meet these goals.

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 and labour and on farmer profits. This goal was not achieved to the same extent in Eastern Europe largely due to the socioeconomic and political conditions, 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 to a large extent on resources outside NAE, which has not only resulted in inequity but also hinders meeting development and sustainability goals outside NAE (see Chapters 2 and 3 of this assessment). 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 (see Chapter 3). 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 (e.g. species loss, soil erosion). As discussed in the following subchapters, the attempts of NAE to assist by means of AKST in reducing hunger outside NAE were only partially successful.

The potential of AKST to contribute to meeting development and sustainability goals might have been considerably greater if the scope of AKST had broadened earlier and not only since the 1990’s, to embrace whole food systems integrating all its 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) with varied perspectives of their actors and of multiple disciplines. This broadening of the view helped AKST on a new track of providing knowledge of the kinds of food systems, which would help to meet the goals and how such food systems might be achieved. AKST has now more potential to cope with the varied societal contexts and preconditions and strive for diverse systems with synergy among the different dimensions of sustainable development.

Approaches and tools of AKST

The increasing deficits 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 development and sustainability goals. Since the 1970s, the problems caused by these structural changes in AKST were relieved through a gradual emergence of more systems oriented 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 is more widely accepted as the preferred 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 but still 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 as well as disciplinary traditions in funding and merit systems have created disincentives to interdisciplinarity. Demands have increased for appropriate education and training to understand diverse science philosophic approaches, for conceptual tools to facilitate the process and for the development of interdisciplinary review systems and publication channels. Transdisciplinarity and participation (4.4) towards governance by the relevant agrifood system actors (including those relating to rural livelihoods, environment and the poor) have been found to require some degree of 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.

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.

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. AKST has focused increasingly on value addition through industrial, high-technology input development and food processing. 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.

Public funding in AKST-related research tended to stagnate since the mid-1970s in many parts of NAE. In recent decades increasing recognition of environmental and social problems has gradually caused a shift in allocation of public funds towards reducing negative externalities. 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 emphasizes the need to develop integrative approaches, to avoid decline of chances of NAE AKST to help meeting development and sustainability goals.

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. 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 and increased transparency, it has been suggested that at worst it also has resulted in extreme competitiveness, suboptimal use of public resources (including increased bureaucracy) and loss of scientific commitment to public goods and long term goals. These changes might hinder the evolution of partnership-based knowledge networks which would help with achieving 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. Therefore, also new forms of review practices and contract arrangements have been sought for. In Europe, competitive grants and a merit system based on quantification of publications increasingly encouraged method based R&D at the expense of problem oriented agricultural 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 of these programs was different from that of the IAASTD.

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 development and sustainability 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.

Financial resources of the world AKST have further concentrated spatially in NAE and in a few large transition economies. International R&D increasingly faced restrictions set by donors for use of funds. Part of the expert community claims that the international significance of NAE AKST in terms of meeting development and sustainability goals has declined in the latter half of the period. Others suggest 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. NAE AKST sciences have focussed increasingly on basic sciences, high-tech approaches, industrial applications and consumer concerns and a higher proportion of food system relevant R&D has been funded by companies. Spill over of AKST from NAE to developing countries is thus declining. The introduction of regulatory policies such as intellectual property rights, biosafety protocols and trading regimes are seen by many as further endangering equity between NAE and the rest of the world. Conventions on access and benefit sharing have been, however, introduced 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 development and sustainability goals.

Drivers of NAE AKST in relation to development and sustainability goals

In the period since the Second World War the main direct drivers of NAE AKST in relation to development and sustainability goals were new KST and shifts in paradigms and societal 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 in 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 contribute to meeting development and sustainability goals of the present assessment a stronger focus on a wider range of public goods and thus a paradigm shift towards a bigger public role in AKST seems to be required alongside the emerged shift towards more comprehensive adoption, application and institutionalization of horizontal (sciences), vertical (food system actors) and contextual (societal and ecological circumstances) integration as well as collective learning (societal learning) within NAE and in the international context.

4.2 Historical trends in the organization of scientific knowledge generation

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 such as “in ten years, no one child shall go to bed hungry” or in terms of “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) (see Chapter 2). 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 though there has been a considerable decline in the proportion of people undernourished in the developing world, there has not been a big change in the absolute numbers of the undernourished since the late 1970s (Falcon and Naylor, 2005). Productivity of labor and land in NAE has increased partly at the expense of limited resources (e.g. land use for fodder export) 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.

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, 2005). 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. 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 publicly funded organisations. 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 IPRs 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).

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 (Box 4.1; Figure 4.1).

[Insert Box 4.1]
[Insert Figure 4.1]

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

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 more and more collective in nature. The number of co-publications has increased in virtually all fields and in some areas experiments can involve tens or even 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. Countries in NAE today spend up to 4% (Sweden) of their GDP on research and development (US, 2.7%; EU15, 1.9%; Russian Federation, 1.2%; Canada 1.9%) (OECD, 2006a).

The increasing importance of knowledge, innovation and technology development for the economy together with globalization have made the world economy more dynamic. Diffusion of knowledge relevant to innovations throughout the economy is extremely important and here the traditional linear innovation model has shown weaknesses (Stokes, 1997). The systemic or interactive model of innovation, currently broadly accepted as a representative picture of how the innovation-driven economy works, postulates the need for dynamic and flexible structures and processes (OECD, 2002). While non-economic institutions often continue to develop along the earlier path (OECD, 2005c), a third-generation of an innovation policy (going beyond the linear and interactive models) is emerging. It calls attention to the process of accommodation, especially in the area of governmental science, technology and innovation policy (OECD, 2005a, b and c). This horizontal process requires governments and institutions to be more flexible and to integrate policy formulation and implementation 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. Key barriers, based on case studies in different OECD countries, 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.

4.3 General trends of paradigms in societal context

4.3.1 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: technology development and rising real wage rates in the non-farm sector. The agricultural sector has undergone a major economic and social change (see Chapter 2) 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) (for further details on changes in labor see Chapter 2). 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) as well as mechanization. With the number of farms declining and aggregate output growing, average output per farm grew rapidly (see Chapter 2 for changes in farm size and modernization of farms).

The main driver for the development of AKST in NAE after the Second World War has 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. Policies that led to a decline in real food prices greatly aided the growth of cities and allowed the rising living standards in North America and Western Europe. In Central and Eastern Europe industrialization of agriculture took place only after the Second World War as part of a planned economy and was more variable. 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 (see Chapter 2 of this assessment) 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).

Public AKST and AKST more generally, contributed to the industrialization and development of productivity. 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 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. 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 (Busch et al., 1984; Huffman and Evenson, 2001) reported that. 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. 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 (OTA, 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

[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).

farmers and (iii) improve agricultural productivity through technical progress and rational production systems that would employ labor more efficiently (see Chapter 2 for further information on CAP, trade and tariffs).

4.3.2 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 which started with Cooperative Wheat Production Program in 1944 to increase wheat yield in Mexico. This program involved the Rockefeller Foundation and the Mexican Ministry of Agriculture. It involved breeding high yielding, disease resistant wheat varieties and combined them with the use of artificial fertilizers, irrigation and pesticides. As a result of the program Mexico became a net exporter of wheat by 1963. A similar approach was applied in Asia with wheat and rice, which also led to impressive yield increases. This strategy 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 (see 4.5.1). 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, 2008). 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. Overall the Green Revolution is credited with saving over a billion people from starvation (Buhler et al., 2002; Evenson and Collins, 2003). Initially there were high hopes in translating the Green Revolution to Africa, but these attempts failed, possibly due to challenging socio-ecological conditions and because farmer’s goals are different to those in Asia (Conway, 1997).

After the initial enthusiasm about the successes of the Green Revolution a whole catalogue of criticisms emerged from the late 1960s onwards. Social concerns included that the practices introduced were often not appropriate or accessible for small-scale farmers, that there was little R&D of the staple crops of the most food insecure and that the reliance on external inputs led to indebtedness of a proportion of the farmers. Environmental concerns pointed to that the building of big dams required for the new irrigation schemes resulted often in flooding of farmland, excessive use of chemical inputs leading to water pollution, soil degradation due to agricultural intensification and more extensive use of non-renewable energy sources. Mixed cropping was replaced with monocultures of single varieties and landraces of crops were lost. Other means of yield improvement tended to be ignored by farmers and crops grown for subsistence gave way to the production of cash crops (Van Keulen, 2008; Falcon and Naylor, 2005; Buttel, 2005).

Subsequently approaches that emphasized the multidimensional effects of technologies aiming 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 Integrated Pest Management (IPM), on-farm conservation, farming systems research (FSR), farmer-oriented approaches and participatory research, sustainable agriculture and integrated rural development (see 4.4.1). CGIAR, in collaboration with national research centres and universities, was extensively involved in IPM programmes and habitat management strategies for parasitic weed and pest control (Cook et al., 2007). FSR approaches, which relate to the whole farm rather than individual elements, taking into account also traditional farming expertise, household goals and constraints (Stephen and Hess, 1999), rapidly became popular and supported by many donor agencies (Brown et al., 1988). As the limitations of the FSR approach became apparent, the agroecosystem analysis (AEA) approach was promoted. It broadened the perspective to taking into account the long term health of the wider ecosystem (Stephens and Hess, 1999). 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).

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. Small farmers increasingly started contract production under large farm owners. In some cases farmers lost their land being unable to pay off credits used to finance external inputs, 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, 2008). Developing countries have also responded to the increase in demand for food produced without chemical inputs exporting organic produce to serve NAE markets, a development of interest to poor and remote farmers. In recent years, the use of genetic engineering techniques to accelerate plant breeding has resulted in some successes. E.g., the introduction of insect resistant Bt cotton in China has been reported to improve yields and yield security as well as reducing insecticide use and cases of pesticide poisoning in farmers (Pray et al., 2002). The transgenic techniques have also raised a lot of criticism due to inequity in terms of access and feared environmental and health risks.

Global insecurity, civil conflicts and lack of democracy have continued to be major problems causing food insecurity (e.g. 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 (e.g. Lappé and Collins, 1988; Falcon and Naylor, 2005).

4.3.3 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).

[Insert Box 4.2]

One example of an ecosystem approach is organic food and farming (OF). Organic farming is based on the principles of health, ecology, fairness and care (IFOAM, 2005), emphasizing animal welfare, which in the 1990s raised wide concern in the society (see Chapter 2). 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 7 million ha in 2006, representing about 3.2% of the European field area (and 4% of that in the EU) (Institute Rural Sciences, 2007). 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 (El Titi, 1992; Wibberley, 1995; IOBC, 1999; Morris and Winter, 1999). Research on various aspects relating to OF and IFS has been taking place in NAE since the late 1970s in response to the environmental side effects of intensive farming practices (see Chapter 2).

The inherent conflicts that occur among environmental, economic and social costs and benefits of agriculture (ACRE, 2006) were increasingly understood. Approaches taking into account the whole food chain started to be developed in the 1980s. In the 1990s food systems approaches emerged, particularly within NAE, in an interaction with the emergence of alternative food systems initiatives (see Chapter 2). These approaches aimed not only to take into account environmental, economic and social aspects but also covered the whole food chain, from inputs to waste management and to support systems related to food, including institutions such as values and norms (see e.g. Dahlberg, 1993; Tansey and Worsley, 1995). Proceeding simultaneously on all the dimensions of sustainability remains a challenge.

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.

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).

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, 2005). 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. 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 Van Keulen, 2008). Further, 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, 2008).

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.

4.4 Changes in the integration of perspectives within AKST

Integration of perspectives within AKST has several dimensions, integration among scientific disciplines and actors representing multiple interrelated goals (e.g. different dimensions of sustainability, different policy goals), system levels (e.g., loops in the food chain, rural development), as well as spatial (local, national, global) and temporal scales (short- and long-term dimension of sustainability). Integration within AKST refers also to integration among education, research and extension. Integration between AKST and KST is also of interest. Integration and disintegration may take place in terms of approaches, methods and conventions of science and innovation, as well as through development of organizational structures.

4.4.1 Evolution

In the past AKST was well integrated, if informally, with practical agriculture and beneficiaries as well as among the emerging disciplines. This changed at the time when the disciplinary basis of universities and research institutes was established. Distancing occurred both in relation to the practitioners and among emerging disciplines (i.e. vertical and horizontal disintegration). This distancing was more extensive in Europe than in the US as the higher education, agricultural research and extension systems of the latter were established in a more integrated way. 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 without this earlier bias. The latter were 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).

Up 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, 1998ab). 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, 1998ab). Additional methodologies were developed to meet the special circumstances associated with agriculture (Huffman, 1998a) and much applied research became multidisciplinary. 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 (Bruun et al., 2005). 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 were much more common than interactions between natural and social sciences (Bruun et al., 2005).

As described above (and in more detail in Chapter 3) the narrow focus in AKST and agriculture after the Second World War 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 representing 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 (Table 4.2), interdisciplinarity and transdisciplinarity (Box 4.3) (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 4.3.2) (Table 4.2).

[Insert Box 4.3]

[Insert Table 4.2]

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 the existing structures and management (Buhler et al., 2002).

For integration of different dimensions of farming and for participation of resource-poor farmers (and later other stakeholders) in R&D, several approaches with different coverage, emphasis and procedures were developed (see 4.3.2). Examples of farmer oriented approaches include 'farmer-back-to-farmer' and 'farmer-first', 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 more and more evolved towards governance (Ashley and Maxwell, 2001). 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 (Sumberg and Okali, 1997).

Food systems approaches (see 4.3.3) often comprehensively involve food system actors to contribute to AKST. 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 (DuPuis and Goodman, 2005). 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 have great potential 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, educational programs taking into account the multiple roles of agriculture and more problem- and improvement-oriented pedagogical solutions (Delgado and Ramos, 2006). 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.

Many analysts conclude from the experiences with international AKST that the constraints faced by agricultural organizations and systems are often institutional in nature (Byerlee and Alex, 1998) and that formal and informal organizations need to closely interact. Consequently, science for agricultural development has become 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 (2005) (in accordance with OECD, 2005abc) “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”.

4.4.2 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.[3] 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, disciplines can be interpreted as just administrative academic artifacts, which have lost their significance as an organizing principle of science during the last quarter-of-century (Lele and Norgaard, 2005). For 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 suggest forgetting disciplines and thinking in terms of scientific community (Lele and Norgaard, 2005). 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.

4.4.3 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 are become more widely accepted in education, research and extension and in some contexts are increasingly demanded by funding organizations. Participation is also an approach increasingly demanded by donors of international research funding.

[3] 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).

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). Seven major barriers for interdisciplinarity exist: structural, knowledge, cultural, epistemological (i.e. relating to the theory of knowledge), methodological, psychological and reception barriers (Bruun et al., 2005).

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 that scholars who review interdisciplinary project proposals have no training in the quality criteria for interdisciplinary research and that boards of reviewers often don’t cover the breadth of knowledge required to give full justice to interdisciplinary research proposals. Based on interviews with highly regarded scientists, main quality criteria for interdisciplinary research include: (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) (Mansilla and Gardner, 2003). Scientists throughout much of NAE are primarily based on their refereed publication output and its impact (measured in terms of impact factors and citations). Scientific journals with high impact factors tend to have little interest in applied interdisciplinary research and often have a disciplinary orientation.

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 (Bärmark and Wallen, 1980; Porter and Rossini, 1984; Bauer, 1990; Duncker, 2001; Pawson and Dovers, 2003; Helenius et al., 2006; Kahiluoto 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). The creation of “trading zones” for exchange and “interlanguages” (more or less elaborate) may be required for successful cooperation across disciplinary boarders (Duncker, 2001). 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. 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. 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 (Rao, 2005; Britz et al., 2006; Chetty et al., 2006). It has contributed to inequity and inefficient use of AKST (Bouma et al., 2007).

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 and it has been suggested that for integrated approaches to be feasible and to become more commonplace, institution-level changes in curricula, incentives, evaluation criteria and accountability would be required (Lele and Norgaards, 2005).

4.4.4 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 in some countries in NAE. 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 particularly in Western Europe in the name of integration, streamlining and quality control have resulted in cuts in funding of disciplinary research. This research has long provided essential knowledge for AKST and gradual cuts have caused confusion and disillusionment of scientists involved in such research. This development 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). It might also limit the capacity to respond adequately to current as well as future challenges facing agrifood systems. 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. Finding the optimal balance between integrated approaches and disciplinary approaches has been (and will continue to be) an important challenge. 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).

Balancing the influence of stakeholders in the development of AKST agendas to ensure that funds are focussed on the areas most relevant to society and the environment, has been a challenge (see also 4.5.3.3 and 4.5.5). 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). 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 judging the potential risks and benefits associated with biotechnology are one recent example. Research suggests that in general, people rely on the judgement of trusted others rather than making choices vis-à-vis technologically complex new products in a rational fashion (Grove-White et al., 2000). It is, however, noteworthy that choices of citizens are also contributed to by their value systems, where scientists are no experts.

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) new technologies are perceived to have (Grove-White et al. 2000).

Following 15 to 20 years of evolution, participatory techniques are now accepted as part of the mainstream science for agricultural development, especially in developing countries. Participation is an inherent part in "innovation systems". The difference between one-directional mediation of information and creation of multidirectional, interactive knowledge networks is fundamental (Table 4.2) (Buhler et al., 2002). On the other hand, it has been argued that the more traditional approaches (e.g. technology transfer) have in places been very successful, providing the appropriate infrastructure was present and that increased use of participation techniques as a research tool has not had a clear impact (Bentley, 1994). Real impact would require more than short-term technology development efforts (Humphries et al. 2000). Seeing farmer participation in research primarily as a route to the empowerment of local populations and almost independent of any eventual research outputs has been questioned (Sumberg et al., 2003).

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. The integration of different structures carries the risk of increasing the administrative burden and wasting funds where it has led lead to an additional layer of bureaucracy. Approaches in integration that do not increase the layers of bureaucracy may be a challenge but would be a more efficient use of limited resources.

4.5 Development of structures, funding and agenda of AKST

4.5.1 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 (Hayami and Ruttan, 1971; Evenson, 1983). 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, acts of Congress assisted the states in establishing land-grant colleges to teach agriculture and applied sciences (in 1862), carry out agricultural research, establish the land-grant experiment stations (in 1887 and 1890) and authorize statewide informal education at colleges (in 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, e.g. in chemistry, mechanization and 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 4.3), 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. The public extension service is still poorly developed. 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). In 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, easy access to important advances in related sciences and scientific methods seemed to be of major importance for success (Huffman, 1998). 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, agrifood 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 4.3]

International agricultural R&D (see also 4.2.2) 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% by the early 1980s (Buhler, 2002).

4.5.2 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 (see 4.5.3) 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 agrifood 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) (see 4.5.4).

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. During the 1990s, the shortcomings of the public research model then also contributed to the gradual emergence of private sector/broadly market-oriented reforms in agricultural R&D investments (see IAASTD Global report). 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. Governmental science policies were also modified to broaden the scope of agricultural R&D and increase its efficiency (van der Meer, 1999; Huffman and Just, 2000; Rubenstein et al., 2003). 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.

In a study (Alston et al., 1998) of public agricultural R&D during the last quarter of the 20th century in developed countries (using the five OECD countries US, Netherlands, UK, Australia and New Zealand as case studies) the following major institutional changes were identified: (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.

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).

4.5.3 Development of funding and agenda

4.5.3.1 Development in NAE

Public agricultural R&D expenditures

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. Alston et al. (1998) analyzed the data available for 22 OECD countries[4], which show that agricultural R&D spending in the OECD grew on average by 7

[4] 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.

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. Some NAE countries had higher growth rates, e.g. the annual growth rate was 4.2% in the Netherlands for the period 1971-81. However, in the 1980s occurred a further decline in real public agricultural R&D expenditure growth rates in many regions of NAE (Figure 4.2, Table 4.4). 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% and expenditure even declined in the UK by 0.2% over the same period.

[Insert Figure 4.2]

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 in NAE 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 and 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.

U.S. federal funding for extension has been declining in scope for more than a decade and support for agricultural experiment stations is 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.

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 the 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 in 28% over the same period.

Public R&D expenditure relative to the value of agricultural output

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 (Alston et al., 1998). The average science and technology research intensity ratio for the countries 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 analyzed countries (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% (Figure 4.3). 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, 2001). A meta-analysis 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 (Alston et al., 2000). These results imply that equally large returns to current spending on agricultural R&D will also be feasible in the future (CGIAR Science Council, 2005). 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, 2005). The US is also increasing funding for more basic agricultural research (Danford, 2006).

[Insert Figure 4.3]

Privatization of R&D

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 in public sector organizations and universities and thirdly by performing research using public funds. There was also a net flow of public funds to private research (Alston et al., 1998).

Investments of the private sector in agricultural R&D have generally increased since the early 1980s. Growth of the private sector spending slowed at the end of 1990s but the balance continued to shift towards private sector funding. Privately performed R&D has become a prominent feature of agricultural R&D in rich countries including most countries in NAE (Alston et al., 1998; Rubenstein and Heisey, 2005) and constituted by 2000 around 55% of all agricultural R&D in developed countries (Pardey et al., 2006). The relative importance of private agricultural R&D in total agricultural R&D varies, however, between countries. 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) (Figure 4.4, Table 4.4).

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. However, there is concern that the shift towards a higher proportion of privately funded agricultural R&D moves the focus too much away 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 remains 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 (Morris and Winter, 1999; Walker, 2001; Voluntary Initiative, 2007).

[Insert Figure 4.4]

[Insert Table 4.4]

Shifts in R&D agendas

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).

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[5] and the Rural Economy and Land Use Programme (RELU)[6] 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).

Funding and scope of extension

There has also been an increasing involvement of the private sector in agricultural extension (Umali and Schwartz, 1994). The last decade has seen increased demands on the expertise of agricultural advisors, particularly in respect to agri-environmental issues. Yet at the same time public funding for extension services has been reduced throughout much of NAE, which has weakened the links between science and application (Ingram and Morris, 2007; Lambert et al., 2007). Public extension systems have been substantially down-sized or phased out altogether in some European countries (Read et al., 1988; OSI, 2006). In North America and Western Europe, technical support to farmers is now to a large extent 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.

[5] http://ec.europa.eu/research/fp6/pdf/fp6-in-brief_en.pdf
[6] http://www.relu.ac.uk/ (accessed 27 Feb 2007)

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., 2000). There has also been a switch of funding that support farmers' activities to control farming business and to address issues of negative externalities. The emphasis on control is to a large part a result of concerns about issues such as consumers' freedom of choice and crises like BSE, foot and mouth disease as well as Avian influenza. 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. Farm visits by advisors still are the most effective of all methods of communication and the most valued by farmers (Ingram and Morris, 2007). 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 seem also to face problems serving the increasing numbers of part-time farmers (Suvedi et al., 2000).

Recent developments

Governments of the OECD countries 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).

4.5.3.2 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, 2005). 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% from the world's total spending in 1995 to

0.33% in 2000, which represents a decrease by almost 10%. These 80 countries account for 7% of the world's population and 1.7% of the world's GDP (CGIAR, 2005).

Concerning agricultural research, over the past two decades, worldwide public investments have increased by 51% in inflation-adjusted terms (from an estimated $15.2 billion in 1981 to $23 billion in 2000) (CGIAR, 2005). However, also agricultural R&D has concentrated in a handful of countries. 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 with two decades before (CGIAR, 2005). Similarly, five transition economies (China, India, Brazil, Thailand and South Africa) accounted for 53% of the developing world's agricultural research, up from 40% in 1981. 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, 2005).

Spillovers of science and technology are increasingly recognized as an important feature of the history of agricultural development (CGIAR, 2005). 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 (Alston, 2002). For example, research conducted in CIMMYT and IRRI in developing countries provided large economic benefits for the US, due to technology spillover (Pardey et al., 1996). 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, 2005).

A central element for research and donor organizations in NAE has been the provision of advanced training to help capacity building, so that individuals and institutions in developing countries become more self-reliant in identifying and executing AKST. Capacity building is generally targeted to individuals, e.g. scholarships and fellowships. Examples include IARC Fellowships (CIMMYT, Vavilov-Frankel/IPGRI), Generation Challenge (CGIAR), UN, TWAS, IFS, Commonwealth Scholarship and Fellowship Plan (CSFP) and fellowships through research organizations (e.g. Rothamsted International) and universities (CSFP, 2007; Generation Challenge Programme, 2007; IFAR, 2007; Rothamsted International, 2007). However, although money is provided for training, there is usually no funding to help scientists to continue the work and training received when returning to their home institutes.

Changes in funding priorities brought about by government policies in European countries lead to a gradual erosion of scientists qualified to work in agricultural research for developing countries. There has also been a fragmentation of the researcher skills base, so that experts are spread amongst a large variety of research institutes, universities and non-governmental organizations, rather than a small number of specialized departments. The decline in expertise has been exacerbated by the closure of undergraduate courses in agriculture (NRI, 2002; Science and Technology Committee, 2004; Delgado and Ramos, 2006).

4.5.3.3 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 in the global report of the IAASTD.

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 (including 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.

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 by 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. The budget of CGIAR has started to increase again in the present century with an average annual growth rate of 6.1% (CGIAR, 2005). 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, 2005).

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 (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 (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; CGIAR Science Council, 2006).

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 (Falcon and Naylor, 2005). Agriculture's share of the total World Bank's lending fell from 25% in the mid-1980's to 10% in 2000) (World Bank, 2003b). In 2000, 37% of the world agricultural R&D was performed by private firms, but 94% of that in developed countries; while in many developing countries the share of the private sector in agricultural research continues to remain insignificant.

There has been a widespread scaling back in investments in public R&D in agriculture among NAE 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 (Pardey et al., 2006). These developments are likely to affect productivity prospects in NAE and spillover of ideas and technologies to poor countries. 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.

4.5.4 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).

Education

The number of students in agricultural sciences have decreased in North America and Western Europe during the 1990s, a process that has continued into the present century. In contrast, student enrolment in food sciences and engineering as well s nutrition and dietetics has increased. In Canada, for example, student enrolment in food science and engineering has increased by 62% since 1996 and student enrolment in nutrition and dietetics by 53% while student enrolment in agricultural sciences has dropped by 21% over the same period. Agricultural science disciplines are under increasing budget pressures at universities as well as at other research organizations (van der Meer, 1999; Delgado and Ramos, 2006). Also, 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)

Changes in paradigms, implications of increasing globalization and complexity of the rural world, the decline of employment and incomes in the primary sector, complex relationships between production and sustainability, cultural resistance to change of traditional societies and a decline in political influence of rural areas all increasingly challenged traditional higher education in agriculture (Delgado and Ramos, 2006). The syllabus in agriculture lagged behind society demands, student numbers decreased and university reorganizations led to the close of more and more agriculture related faculties. Initiatives have been started to increase internationalization and cooperation as one component of the drive to help higher education organizations meet these challenges (Delgado and Ramos, 2006).

Changes in research structures and management

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; van der Meer, 1999; 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., 2003). 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 suggests 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., 2003). 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.

4.5.5 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). The size and power of different interest groups can have a major impact on the funding for and direction of AKST (see the global report of the IAASTD). 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). Different approaches are likely to be appropriate for different situations and regions. An important factor in making 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). Barriers and risks that integrative and participatory approaches have encountered have been described above (4.4.3 and 4.4.4).

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). In recent years farmer participation in the development of AKST has increased again in NAE (Romig et al., 1995, 1996; Walter et al. 1997; Wander and Drinkwater, 2000; Dik, 2004; Groot et al., 2004; Morris, 2006; Ingram and Morris, 2007; Timmer et al., 2007). Public consultation processes have been extended to include a wider range of voices in the setting of agendas for publicly funded agricultural research (OSI, 2006).

Concerns have been expressed that the increased influence of some sections of the private sector in the setting of public research agendas have the potential for biased benefits (Ulrich et al., 1986; Constantine et al., 1994). For example, in the US the agricultural research agenda is today heavily influenced by the private input sector and, to a lesser extent, by processing industries. There is also concern that less research is made available in the public domain due to the increased extent of research being conducted and funded by industry, which needs confidentiality to protect investments and stay ahead of competitors (Buhler et al., 2002). The central role of AKST as a driver of industrialization and structural change, especially but not solely of agriculture, has also raised debate about whether even publicly funded agricultural research is targeted to the full range of user and citizens' groups (BANR, 2002).

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. In Central and Eastern Europe the number and influence of policy of civil society groups increased substantially after 1989. 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 still more influential 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. Civil society organizations 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 as observers (UNEP, 2002). 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 (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 of AKST in recent years. 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.

In the international research, the colonial period was characterized by a top-down approach and a focus on cash crops (see 4.3.2). Then 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 and thus linkage of agricultural R&D to clients was weak. Indigenous agricultural systems received negative rather than positive attention (Boserup, 1965). Since the late 1970s, participatory approaches involving farmers have become the mainstream. The international donor organizations and contributing governments are influential beneficiaries and clients. Their importance has increased further during the last decade, due to the increasing constraints set by donors in respect of the use of funding (see 4.5.3).

4.5.6 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 unusually high productivity gains stemming from 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.

Competitive grants and short-term contracts

To improve productivity the share of funding given out as competitive grants has been increased since the 1970s (Huffman and Just, 2000; Rubenstein et al., 2003). Also, the increasing role of the private sector in management of the public agricultural 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 (Schultz, 1980, 1982, 1983, 1985; Huffman and Just, 2000). 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).

Other topics discussed as a response to the dominant developments included the character of agricultural research as innovation and the difference between setting efficient incentives and organizational structures for industrial production/marketing and for innovation processes (Schultz, 1980; Anderson and Hardaker, 1992; Huffman and Just, 2000).

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). The main intentions of the shift towards more competition were to ensure high quality science, high overall productivity and transparency. However, the shift has also had other fundamental consequences. The increase of managed competition in public funding 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 4.4.5). 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 of agricultural R&D where there is no sustained funding, even if there are high pay-off potentials (not necessarily economic profits).

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 agrifood 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). The drive to short-term funding has also resulted in a reduction in NAE scientists with overseas experience in agriculture.

Based on principal-agent theory, the move from formula/program funding to research grant funding may be partly counterproductive for agricultural research due to too much of the best scientists' time is used for proposal writing/evaluation and signalling activities, the risks of conducting research being imposed unduly on scientists, and review committees not sufficiently sampling diversity (Huffman and Just, 2000). 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). Others note, that in the United States, competitive grants have never reached more than about 15% of total USDA research funding to States, nor more than 17% of total public agricultural research expenditures (Rubenstein et al., 2003; Rubenstein et al., 2007). Rubenstein et al. (2003) showed empirically that the US competitive grants focussed more on basic research and were distributed among fewer states than other instruments.

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 agricultural research incentives, these policy changes resulted in an immediate increase in the institutional risks of research (Huffman and Just, 2000). The short-term benefits of these shifts may not outweigh the longer-term costs and agricultural research organisations may not be able to retain important expertise (Alston et al., 1998). 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.

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. For example, development as a field within economics may be disappearing due to "the path-dependent and disequilibrium nature" being at odds with the mathematical directions of the present-day economic theory (Falcon and Naylor, 2005).

Privatization

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 (see 4.6). The share of private sector expenditure in total agricultural R&D has increased to the extent that it exceeds public sector expenditures (4.5.3) (Fuglie et al., 1996; Huffman and Evenson, 1993; Huffman and Just, 1998). This trend is seen by many as not benefiting society as it is seen as shifting 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). 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, which resulted in more involvement in technology transfer that yielded royalty income over gratis technology transfer. This change is seen by some as being to the detriment particularly of smaller farmers (Buttel, 2005).

Alternatively, it has been argued that it is a benefit that competitive funding helps to change the direction of public towards more necessary basic research (NAS, 1972; Rockefeller Foundation, 1982; NRC, 1994, 2003) and that more basic research is necessary to maintain historical rates of agricultural productivity growth. In this view, if basic research were reduced, applied research would eventually become unproductive. several potential advantages of competitive grants: responsiveness and flexibility; potential to attract the best talent through open competition; potential, through professional and peer review, to ensure that research resources flow in those directions with the greatest expected payoffs; and capacity to balance and complement other research resources and programs (Alston and Pardey, 1996). Hence, it can be argued that finding an optimal balance between competitive and programmatic funding mechanisms may be a key.

The view has further been expressed (Alston et al., 1995; Alston and Pardey, 1996) that agricultural research policy is “a blunt and ineffective instrument for objectives other than economic efficiency” and that attempts to meet other objectives through public agricultural research policy often incur “transactions costs that are not borne equally.” This is particularly the case when there are other policy instruments (e.g. tax and income transfer policies) available to also address equity objectives through public policy. The way the "national economic pie" is sliced among varying groups will be affected by the choice of research priorities and in some cases (particularly in countries with weaker institutional structures) the use of other policy instruments may be relatively unavailable; yet the trade-off between efficiency and other objectives "should be limited" (Alston and Pardey, 1996).

Indeed, a number of arguments have been advanced (Ingram and Rubenstein, 1999; Fuglie and Schimmelpfennig, 2000; Brennan and Mullen, 2002; van der Meer, 2002) for the promotion of public-private cooperation in agricultural research: (i) providing a natural response in the provision of "mixed" or "hybrid" goods that have both public and private characteristics, (ii) enhancing research efficiency by enabling the public sector focus resources on areas where private incentives are relatively weak, (iii) providing different alternatives for maintaining adequate levels of basic research (e.g. by enabling the public sector to concentrate more on basic research while the private sector focuses on nearer-market research), (iv) encouraging more innovative efforts and investments by the private sector, (v) increasing business activity that promotes competition and as a result leads to the supply of better or cheaper products and services; and (vi) improving the public reputations of companies and public research managers. Therefore these public policy choices and trade-offs are not simple "either-or" propositions.

Rationalization of structures

The trend towards making public agricultural research facilities more cost effective had a positive economic impact where such streamlining took place in response to changes in scientific methods and to take advantage of new economies of size and scope. However, where this "rationalization" was used merely as a justification for reductions in 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 European countries contributed to a serious fragmentation and weakening of the disciplinary research base and that the strategic planning of public sector funding organizations sometimes 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 always been sufficiently included in the evaluation of areas of research considered for closure (OSI, 2006).

Reallocation of research resources

Reallocation of public research resources away from near-market research programs to environmental and food safety issues is seen by many 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 potentially negative consequence of 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).

One conclusion of the latest review of the CGIAR system (World Bank, 2003a, b) (see 4.5.3) 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).

4.6 Development of Public Control of Agrifood Systems

The rise of different forms of control of agriculture has had profound effects on agriculture in NAE over the past 50 years. 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 for example biotechnology.

4.6.1 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.

Example 1: Pesticide regulation in Europe and the US

Pesticides are presumptively dangerous under US and also EU laws. Accordingly, each regulatory system establishes conditions under which they can be used without evidence of unreasonable harm to humans or the environment and these become mandatory for users. Scientific analysis of pesticide safety has advanced considerably since the 1960s and thus factors that were unknown 40 or 50 years ago are now considered in evaluating pesticide safety.

More skeptical observers have argued that the regulatory systems that have developed since the 1960s for pesticides have been ‘reactive’ in that the industry and its products are controlled by a system set up in response to evidence of adverse, sometimes unexpected, impacts that have been found in products. Once a hazard to health or the environment has been demonstrated, new products in development are screened to ensure that they do not give rise to similar hazards. The regulatory system is thus built up slowly as new products exhibit different, sometimes unexpected, hazards. Decisions about the need for and form of, regulation are taken on the basis of the best available scientific evidence and in relation to the relevant costs and benefits (Tait and Levidow, 1992).

An example of this process is the evidence that accumulated in the 1960s and 70s that commonly used organochlorine insecticides were harming wildlife (Moore, 1987). Thereafter, regulations were introduced to ensure that chemicals which were highly persistent in the natural environment (previously seen as a desirable attribute) would not be approved for use. Potential persistence in the environment then became a reason to reject a new pesticide from the research and development pipeline at a very early stage. A more recent example was the appearance of pesticide residues in drinking water in the EU. Consequently, the Drinking Water Directive (Council Directive on the Quality of Water intended for Human Consumption, 80/778/EEC) prohibited the use of any pesticide, residues of which appeared in drinking water at a concentration of greater than 0.1µg per litre. High mobility in soils, seen as an indicator of the potential of a chemical to reach drinking water supplies, became a reason for early rejection of a chemical from the product development pipeline.

This intensification of pesticide regulation has continued to the present day, although many other regulatory and policy areas have been subjected to de-regulation initiatives with a view to encouraging industry competitiveness. This has created a barrier to entry for small companies on the pesticide sector. Some interesting contrasts in impact on industry strategies can be found, however, between Europe and the US. The US Food Quality Protection Act (FQPA) 1996 had, according to interviews with agrochemical industry managers, fundamentally changed the way companies respond to regulatory signals from the US Environmental Protection Agency (EPA) in the regulation of pesticides (Yogendra, 2004; Tait et al., 2006). The new safety standard – reasonable certainty of no harm – that is required to be applied to all pesticides used on food crops is linked to a system which expedites the approval of safer pesticides (www.epa.gov/oppfead1/fqpa) on a ‘fast track’ basis creating a new competitive advantage as an incentive for development. Such instruments selectively enable some companies (those that have such products in their development pipelines) to gain a competitive advantage over others and can in a very short space of time alter the behavior of a whole industry sector in a positive direction.

In contrast, the European Drinking Water Directive (80/778/EEC) regarded all new chemical entities as equally hazardous. For an example, while one member of the strobilurin fungicides group with a favorable environmental and health related profile was the first product to be registered under the FQPA fast track system, this group narrowly escaped rejection at an early stage of product development because of the mobility in soils and hence the danger of falling foul of the EC Drinking Water Directive. The regulatory systems currently in operation reflect accumulated evidence over decades as we have learned more about the hazards of different classes of chemicals and removed some chemicals from approved lists, opening up opportunities for companies to develop new products to fill particular market niches.

In considering the interactions between regulatory systems and agrochemical company innovation strategies, the highly onerous regulatory demands on companies developing new pesticides have created a barrier to entry for small companies that might attempt to compete with the incumbent multinationals which has been increasing steadily since the 1970s. This means that, in the pesticide sector, there have been no innovative small companies developing products which could compete with the strategies of multinationals in pesticide development. Unlike the situation in the information and communication technology sector, one group of companies with a consistent set of innovation strategies and the ability to sustain investment without any commercial returns over very long lead times has been able to retain a dominant position in technological innovation for agriculture for the last fifty years., This dominance of the agrochemical industry over innovation in technology for agriculture had an important influence on public attitudes to GM technology (see below). This is particularly the case in Europe, where public concerns about the conventional farming systems, which formed the main market for products from the agrochemical industry, had been increasing steadily (Bauer and Gaskell, 2002).

Example 2: Regulation of genetically modified crops

Considering the second example of evolution of public control systems in AKST, even more fundamental differences than concerning pesticides, emerged between EU and US approaches to the regulation of genetically modified (GM) crops in the 1980s. This debate was one of ‘product vs. process’ (Tait and Levidow, 1992) with the US considering GM crops as inherently similar to existing products subject to existing regulatory systems, while the EU viewed the process of genetic modification as potentially leading to novel unpredictable properties requiring a new approach to regulation. The analogy most frequently used in the EU was the introduction of alien species with the attendant risks of uncontrollable spread in the natural environment (RCEP, 1989). This distinction has been a major contributor to understanding trade difficulties the US as with the EU.

In the early stages of development of GM crop technology, the difficulty for international harmonization of European and US regulatory systems arose at least in part from the fact that the two regions chose different and largely incompatible analogies on which to base their regulatory systems for GM crops. The European process-based approach to GM crop regulation, embodied in the Directive 90/220, was initially intended to be more precautionary than the US approach (although this notion is debated by US regulators) and also to be temporary, pending the generation of evidence on the safety of GM crops in use. However, the emergence in Europe of an advocacy coalition (Sabatier and Jenkins Smith, 1993) campaigning very successfully against GM crops has resulted instead in a regulatory environment based on a new revised Directive 2001/18 and subsequent regulations, which are extremely restrictive and are unlikely to be compatible with a profitable European industry sector producing both GM crops and pesticides.

Genetically engineered products under development include additional crop species and a more diverse set of traits. They will present challenges for environmental safety evaluation.

In future development and production of GM crops for global markets is likely to be based outside Europe, particularly in the US and potentially also in India and China. If the co-production of GM crops and pesticides, including strategies for using a combination of GM crops and pesticides to give effective insect pest and disease control, becomes the dominant industry strategy, as currently seems likely, then the multinational companies that currently have a strong research base in Europe are likely to move their headquarters to other parts of the world (Chataway et al., 2004; Tait and Chataway, 2006).

In Canada, the regulatory system requires crops with novel traits to be assessed for their environmental safety irrespective of whether they have been produced by genetic modification or conventional breeding methods (Morris, 2007). This applies for example to herbicide tolerant crops, which have been produced using either genetic modification techniques or conventional breeding. Environmental risks associated with the growing of conventionally-bred herbicide tolerant crops and herbicide tolerant GM crops are considered to be very similar if not identical (ACRE, 2006; Morris, 2007). In the EU conventionally bred herbicide tolerant crops can be introduced without prior environmental risk assessment. In contrast, the EU GM directive requires that herbicide tolerant GM crops are not only assessed for potential direct risks but also indirect and management-related risks. Some EU governments currently oppose certain herbicide tolerant GM crops solely because of their management-related impacts on broad-leaved weeds and associated wildlife (Hawes et al., 2003; Heard et al., 2003 a, b; Roy et al., 2003; Beckett, 2004; Bohan et al., 2005).

Regulatory systems could be managed to give appropriate signals to companies developing the technology, to improve on the potential benefits for sustainable farming systems. The earliest products of innovative technologies have usually given only a hint of potential future benefits and innovation progress relies as much on social learning as it does on scientific knowledge (Williams, 2000).

4.6.2 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 (see Chapter 2). 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 (Box 4.4).

[Insert Box 4.4]

There are, however, unresolved issues associated with the development of IPR frameworks at international and national scales, as none of the systems (patents, trade marks, contracts, GI, varieties) offer much protection of rights of farmers and local communities, especially in developing countries. Many NGOs and farmers' organizations are currently active to develop effective protection mechanisms based on traceability and transparency (Bazile, 2006). For a thorough analysis and assessment of roles, impacts and challenges of IPR protection, see IAASTD Global report, Chapters 2 (2.3.1 Genetic resources management) and 3 (3.2.4 Relationships between AKST and coordination and regulatory processes among multiple stakeholders).

4.6.3 Changes in policy goals

Supply driven policies

The recovery from the Second World War of the agricultural sector in Europe, the changes in the share of agriculture in national GDP and in the share of the workforce employed in agriculture in NAE have been described in Chapter 2 of this assessment. Initially 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. When food production started to exceed national consumption, the memories of shortage and of the widespread rural distress of the 1930's meant that governments were unwilling to allow prices to collapse and the emphasis on retaining production capacity was retained and farmers were further helped by a variety of subsidies provided on inputs (OECD, 1967) (see Chapter 2).

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 development and uptake of new technologies the private sector played a major role (see Chapter 2) for the development of new inputs by seed companies, the agrichemical industry as well as lifestock breeders. 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).

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. Within the European Community the issue of surpluses increasingly dominated policy thinking from the late 1970's (see Chapter 2). 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.

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.