THE INNOVATION SYSTEM IN AGRO-FOOD BIOTECHNOLOGY – IS IT EUROPEAN?

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1. Introduction

Research on the innovation potential and socio-economic impacts of biotechnology is mainly looking at biotechnology as a homogenous technology, or focusing on specific subsectors like biopharmaceuticals, bioinformatics, environmental biotechnology or agro-food biotechnology. In the latter field increasing commercialisation and utilisation of GM products can be registered mainly in North and South-America while a quasi-moratorium for GM plants was established which prevents market approval of transgenic plants and derived products in the EU since 1998. In addition, biotechnology applications in the agro-food sector are discussed controversially in the different EU member states. On the other hand, ongoing research activities, public funding of agro-food biotechnology as well as commercial activities (like founding of genomic-based agro biotech start-up companies, implementation of biotechnology approaches e.g. in plant breeding or fine chemical producing companies) can be observed in almost all EU countries. Against this background the question arises: how „European“ is the innovation system in agro-food biotechnology or – in other words – whether the national or the sectoral systems of innovation are dominant in shaping the development of agro-food biotechnology within the EU.

2. Theoretical framework

Innovation is a complex phenomenon, involving the production, diffusion and translation of scientific or technical knowledge into new or modified products and services as well as new production or processing techniques. There is a general agreement in modern innovation that innovation "by no means follow a 'linear' path from basic research to applied research and further to development and implementation of new processes and new products (as it was stated during the 1980s) (Edquist, 1997). Instead, innovation is characterised by complicated feedback mechanisms and interactive relations involving science, technology, learning, production, policy and demand" (Edquist, 1997). In addition, innovation processes occur over time and are influenced by many factors. In consequence, commercial companies almost never innovate in isolation but they interact with "organisations" of different types (e.g. suppliers, customers, research institutions, investment companies, government agencies) and their behaviour is shaped by "institutions" as well (Edquist, 1997) which constitute constraints or incentives for innovation (e.g. laws, cultural or social rules, technical standards).
National Systems of Innovation (NSI)

Due to their complex character, innovation activities represent an ideal area to use system theory approaches for the analysis of such processes on the level of a (national) economy. Since the 1980s a series of "systems approaches" and empirical studies can be registered for this purpose. "National Systems of Innovation" (NSI) is the most frequently used approach of the last decade for understanding the complex relations of the innovation process. The notion of "National Systems of Innovation" was introduced by Lundvall in 1988 (Freeman, 1995). The basic idea of this approach refers to Friedrich List who wrote his publication "The national system of political economy" in 1841 (List, 1841). In the late 1980s, Freeman (1988), Lundvall (1988, 1992), and Nelson (1993) launched a series of studies on national innovation systems.

The NSI approach cannot be regarded as a formal theory, rather it provides a conceptual framework for analysing the specific factors influencing the innovative capabilities of companies (Edquist, 1997). The NSI approach assumes that the innovative capabilities of a firm depend on its ability to communicate and interact with a variety of external sources of knowledge (e.g. other firms, suppliers, users, scientific institutes, service and supporting institutions), as well as on the ability to co-ordinate a variety of interdependent sources of knowledge within the firm itself (e.g. R&D, production, marketing/sales) (Freeman and Soete, 1997). The NSI approach rests on four basic concepts: innovation, learning, system and nation. "Innovation" refers to the activities of companies to develop, introduce and diffuse new products and production processes (Nelson and Rosenberg, 1993).

These processes depend on "learning" from a variety of activities undertaken within companies, on the co-ordination of this internal knowledge as well as its integration with knowledge acquired from external sources. According to Lundvall (1992) learning is regarded as a complex process which involves new knowledge as well as new combinations of existing knowledge. Learning processes draw upon a variety of sources of knowledge and are carried out in a multiplicity of activities in society. In this sense processes of organisational and institutional change and learning are also included in the NSI approach.

Because innovation involves different forms of interactive learning, Lundvall suggests to address it within a "systems approach" (Lundvall, 1992), which is common to all authors dealing with the NSI approach (Edquist, 1997). In general terms, a "systems approach" assumes that the overall performance of a complex of elements depends not only on the characteristics of the single elements, but on how these elements mutually constrain and influence each other. Therefore, it is not sufficient to specify individual elements or constituent parts of the system, but to emphasise the interdependent relationship between these elements or constituent
parts of the system, but to emphasise the interdependent relationship between these elements (Edquist, 1997).

The fourth basic concept of the NSI approach represents a "nation state" which is defined by the boundaries, not only in geographic terms, but also for relatively homogenous patterns of social and cultural values shaping the institutional set up of a system of innovation (Lundvall, 1992), and by the role of the state and its public policy (Edquist, 1997).

A central issue discussed in scientific literature is the question whether geographic national boundaries still can be assumed for the national systems, or whether the process of globalisation has erased them and innovation is now a global process (Ohmae, 1990). Although several studies have been published that find a high degree of globalisation of R&D (Nelson and Wright, 1992, Fransman, 1995, Archibugi and Michie, 1995), other analyses show that R&D activities are to a lower degree subject to globalisation tendencies than processes of production (Patel, 1995, Farina and Preissl, 2000). In conclusion, the representatives of the NSI approach argue that because of differences in public policies, a variety of factors in an NSI (e.g. regulation and standards, public research and education system, property rights, shaping of the financial and banking system, communication infrastructure) vary between nations (Edquist, 1997, Nelson, 1993, Johnson, 1992, Niosi et al., 1992). Altogether, Lundvall et al. (2002) come to the conclusion "that the national level remains important for certain innovation activities".

**Regional and sectoral systems of innovation**

Other critics of NSI have stressed that alternatively (or in addition to) sub-national entities, such as provinces, industrial districts or cities have become more important than the nation-state (de Bresson, 1989, de Bresson & Amesse, 1991). Therefore systems of innovation have been studied on levels below the nation state since the 1990s. In this context a regional perspective has been widely used, although the notion of "regional systems of innovation" is not common in the economic literature. One famous example of the regional approach is Saxenian's study of the electronics industry in Silicon Valley in California and along Route 128 in Massachusetts which focuses on differences in culture and competition between the two regions (Saxenian, 1994). Other examples of regionally oriented analyses of innovation systems can be found in Cooke et al. (1996), Boekholt et al. (1998) and Fritsch and Schwirten (1999).

In addition, sectoral approaches ("Sectoral Innovation Systems") have been introduced in the economic literature as well (Breschi and Malerba, 1997) where the boundaries of the systems are endogenous, emerging from the specific context of the sector. They are based on the idea that different sectors or industries operate under different technological regimes, which are characterised by specific
combinations of opportunity and appropriability conditions, degrees of cumulativeness of technological knowledge, and characteristics of the relevant knowledge base (Carlsson et al., 2002).

**Technological systems**

Another type of systems approaches focuses more on the technology itself and its mediation. The concept of "technological systems" (TS) seems to have been first used by Thomas Hughes (1983) in his study of the electrification of the US railway system during 1880 and 1930 (Carlsson and Stankiewicz, 1995). Afterwards there have been several studies on the development of electric power, railroad, telephone, and air traffic systems in Europe and the USA (Bijker et al., 1987, Mayntz and Hughes, 1988, Ropohl, 1998), using sometimes slightly modified variations of this approach.

Technological systems have been defined as a "network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilisation of technology" (Carlsson and Stankiewicz, 1995). They are based on the dynamic concept of "development blocks" which was introduced by Dahmén in the 1950s (Dahmén, 1989). TS are characterised by knowledge or competence flows rather than the flows of ordinary goods and services, i.e. in this sense TS represent dynamic knowledge and competence networks.

In the presence of an entrepreneur and sufficient critical mass, such knowledge and competence networks may be transformed into innovative "development blocks", i.e. synergistic clusters of companies and technologies within an industry or a group of industries (Carlsson and Stankiewicz, 1995). For the transformation of a knowledge and information network into a development block, the presence of substantial entrepreneurial activity play an essential role. It is not only the task of entrepreneurs to respond to market signals by searching and investing in new technical solutions, but also to create new markets (Carlsson and Stankiewicz, 1995).

Another prerequisite to transform knowledge and competence networks into a development block is the need of a critical mass which is directly linked to the nature of innovation. Dosi (1988) listed five "stylised facts" about innovation and described them with attributes such as uncertainty, science base, complexity, experimentation (learning process) and cumulative character. Hence, the efforts of a few innovators might be "too meagre to stimulate economic development" (Carlsson and Stankiewicz, 1995), thus requiring the interaction among agents with different competencies. This might apply technologically and geographically especially in high technology fields. The development of a TS as well as the
transformation of a knowledge and competence network into a development block depends on the institutional infrastructure as well.

Analysis of the agro-food biotechnology innovation system

All suggested approaches to analyse innovation systems emphasise the high relevance of strategic co-operation among different actors in innovation processes. In addition, the generation of knowledge and "learning" of individuals or organisations is regarded as a vital part of innovation systems as well.

Given the persistence of a tacit\(^1\) share of knowledge in particular in new emerging technological fields which cannot be transferred in codified form, learning is outlined as a key factor of development for innovation systems. The system's capacity to learn in the sense of acquiring new skills is regarded as a crucial factor of competitiveness (Lundvall and Borràs, 1997). Therefore, innovation systems literature has paid a lot of attention to formal and informal co-operation and interaction among firms (Malerba, 2002). In this context a variety of channels – formal and informal, direct and indirect, deliberate and unplanned – for interactions between research organisations and commercial companies are revealed in the economic literature, such as codification of information or ideas (e.g. in scientific publications, patents or in form of prototypes), different forms of co-operations (e.g. joint ventures, joint research projects, personnel exchange), formal or informal contacts (e.g. meetings, conferences, informal interactions, specific networks), as well as formal contractual links (e.g. licenses, contract research, consulting).

There are no examples in the economic literature which intend to analyse the innovation systems of agro-food biotechnology in different countries. In this context in particular the question arises whether sectoral features on a European level or national peculiarities which characterise national innovation systems are main driving forces of the sector. From the system theory perspective of innovation research we ask whether the sectoral (European) or the national systems of innovation are predominant in shaping the agro-food biotechnology sector in the EU.

In order to analyse this question, information on different factors have to be collected. Figure 1 gives a simplified overview of the factors which are regarded as being significant to innovation, the networks in which the relevant institutions and organisations are embedded as well as their inter-relationships. The main components of the framework are networks of knowledge and skills, industry and

\(^1\) Tacit knowledge consists of highly specific technological and other know-how acquired during long processes of learning and cannot be easily transferred between individuals because it has not been stated in an explicit form.
supply, demand and social acceptability as well as finance and industrial development (figure 1).

Figure 1: Network of key factors influencing innovation

Source: Senker et al., 2001

Methodology

The empirical data of this analysis is based on a European research project funded by the European Commission under the "targeted sozio-economic research" (TSER Programme). The project with the title "European biotechnology innovation systems" (EBIS) was carried out between 1999 and summer 2001 by a team of 8 European research groups and co-ordinated by the Science Policy Research Unit (SPRU) of the University of Sussex, UK2. Fraunhofer ISI was the German partner of the project. Within this project a common framework was developed (based on a literature overview) in order to analyse innovations in biotechnology in three sectors (biopharmaceuticals, agro-food, equipment and supplies) in the involved

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2 EC TSER Contract No.: SOE1-CT98-1117 CDG12): This project was jointly carried out by University of Sussex (SPRU), Brighton, Laboratory of Industrial and Energy Economics and Laboratory of Biotechnology NTUA, Athens, University Pierre Mendès France, INRA/SERD, Grenoble, Institute of Advanced Studies Vienna, TNO-STB, Delft, CSIC/IESA, Madrid, BioResearch Ireland, Dublin and Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI), Karlsruhe.
eight case study countries: Austria, France, Germany, Greece, Ireland, the Netherlands, Spain and the United Kingdom. The case studies on these countries provided information on the factors mentioned in figure 1 for the three analysed sectors (including agro-food) of biotechnology applications. Additional sources of information were used for collecting background national or sectoral data. These include available statistical data or results of already performed studies (e.g. on the public funding of biotechnology in the EU). In each of the 8 countries the research teams identified companies which were potentially active in the biotech agro-food sector via desk research. In addition, a company survey was performed in the eight countries in the year 1999 including questions related to company structure, co-operations, technology use as well as product development and marketing. In the agro-food sector 162 companies filled in the questionnaire and participated in the survey. Due to a very limited number of filled-in questionnaires, a detailed analysis of agro-food biotechnology companies cannot be performed for Austria (3 responding companies), Ireland (6 companies) and the UK (6 companies). In the latter country the companies hesitated to participate in the survey due to a very conflicting situation related to the use of agro-food biotechnology when performing the survey. In the other five countries between 12 (Greece) and 59 agro-food biotechnology companies (France) responded to the questionnaires. All data were entered into a common database which served as a basis for the statistical analysis of the sector and will form an important source of information for analysing the innovation system of agro-food biotechnology in these countries. Additional information was obtained through interviews of experts and by screening the available literature on the sector.

3. Empirical analysis of the agro-food biotechnology innovation system

In the following the results of the empirical analysis of the agro-food biotechnology innovation system in the eight analysed countries will be presented according to the four networks of key factors which form the framework of our analysis.

3.1 The knowledge skills network

The current skills and knowledge base in each country is affected in part by the date at which national policies first focused on the support of biotechnology in general and biotechnology in the agro-food sector in particular. The eight countries can be roughly divided into two groups: the first group (France, Greece, the Netherlands and the UK) began to introduce policies to support a biotechnology research infrastructure around 1980. The second group of countries (Austria, Germany, Ireland and Spain) only started during the second half of the 1980s with biotechnology-specific policy measures.
Turning to the 1990s these countries have developed rather differently in terms of public funding of agro-food biotech research. France, Germany and the United Kingdom are spending most public money for research in this sector (Enzing et al. 1999, Giessler and Reiss, 1999). In France and Germany the annual research budget for agro-food biotech amounted to roughly 63 million € between 1994 and 1998. The respective figure for the United Kingdom was 155 million €. Related to the gross domestic expenditure on R&D the German and French funding corresponds to between 0.1 % and 0.2 %, while the British contribution makes roughly 0.7 % indicating the rather high specific funding of agro-food biotech research in the UK.

Greece, Austria and Ireland on the other hand spent the least on the science base during the 1990s with annual budget below 3 million € each (Enzing et al., 1999, Reiss, 1999). Spain has an intermediate position with a fast growing science base and an average annual R&D budget for agro-food biotech between 1994 and 1998 of about 9 million € (Senker et al., 2001). The situation of the Netherlands is difficult to evaluate in terms of subsector-specific R&D expenditure because during the 1990s there was no specific biotech programme directed towards certain subareas of biotechnology, rather biotechnology research was funded within generic programmes. However, since the science base in the Netherlands can be considered as very well-developed it seems to be fair to assume that a considerable amount of the total annual biotech budget of about 65 million € during 1994 and 1998 flew into agro-food biotech.

Looking at the actors generating and transferring scientific know-how for the agro-food biotech sector, different configurations can be identified in the eight countries. Austria and Greece count on a mainly university-based systems where the national universities are the most important actors in the knowledge skills network. In Austria eleven university institutes at six universities and one inter-university research centre are the main university-based actors in the system. In addition, two non-university institutes conduct agro-food biotech-related research. A similar situation can be stated for Greece where six universities are the main actors. In addition, there are few non-university institutions, e. g. of the National Agricultural Research Foundations.

In France, Spain, the United Kingdom and Ireland governmental research institutions are the main actors in the agro-food biotech knowledge skills network. In France among the seven national research organisations INRA with about 500 fulltime researchers in the agro-food biotech sector is the most important player. In addition, 30 universities with various institutions and 5 Ecoles Nationales Supérieures Agronomiques are active with various intensities in this sector. In Spain among the governmental institutions the INIA with 9 regional research centres and the CSIC with 16 institutes are performing most of the agro-food biotech research system. In the United Kingdom the 8 institutes of the Biotechnology and Biological Sciences Research Council (BBSRC) are the key players in agro-food biotech
research: the Babraham Institute, the Institute of Arable Crop Research, the Institute of Animal Health, the Institute of Food Research, the John Innes Centre, the Roslin Institute, the Silsole Research Institute and the Institute of Grasslands and Environmental Research. In addition, various universities in Great Britain are performing related research. In Ireland a number of research centres are active in the sector with the 9 research centres of the TEAGASC being the most important ones.

The Netherlands and Germany finally can be considered as a mixed system where universities and numerous non-university research institutes are performing agro-food biotech research. The non-university institutes in Germany belong to the Max Planck Society which has five institutes which are doing considerable agro-food research and to the Helmholtz Society with one national research centre being active in this area, to the Leibniz Society with four institutes. In addition, five departmental research centres of the Federal Ministry of Consumer Protection, Food and Agriculture are key players in this area. In the Netherlands in general a very strong research base has been build up in agro-food biotech since many years. In addition to 9 universities, the Wageningen Centre for Food Science, the Wageningen Research Centre, two institutes of the TNO and the Dutch Institute for Dairy Research of NIZO perform related research.

3.2 The industry/supply network

In total, we identified 162 agro-food biotech companies in the 8 countries. The foundation of agro-food biotech companies over time changed remarkably between 1980 and the end of the 1990s (figure 2). Between 1984 and 1990 we observe a considerable increase in the annual number of agro-food biotech companies founded. Similar developments occurred also in other biotech sectors such as biopharmaceuticals (Senker et al., 2001).

From 1990 on, however, a downwards trend in foundation activities can be observed for the agro-food biotech sector. This is in contrast to the biopharmaceutical sector were especially in the second half of the 1990s very intensive foundation activities took place (Senker et al., 2001). By far most of the agro-food biotech companies (about 86 %) were independent foundations. Only about 7 % have been founded as spin-offs from research organisations, another 7 % as spin-offs from industry. In other sectors, e. g. biopharmaceuticals or equipment and supplies, only about two thirds of the companies were established independently (Senker et al., 2001).
The analysis of the size distribution of the agro-food biotech firms in the 8 European countries indicates that there are 2 main groups of firms: very small firms with less than 20 employees and medium-sized and larger firms with more than 100 employees. Both groups make roughly one third of the total population (figure 3).
In order to identify similarities or differences between the industrial agro-food biotech sector in the eight countries, in the following some comparisons of selected features of the sector will be presented. The distribution of the agro-food biotech firms among the eight countries reveals a surprising picture (figure 4): Of the three larger countries only France is home of a considerable number of agro-food biotech firms, covering about 36% of the whole population. Germany and the UK on the other hand, count only a low number of such firms, whereby the very low share of the UK is most surprising. On the other hand, besides France some of the smaller countries (in terms of population), namely Spain, the Netherlands and Greece seem to focus on the agro-biotech industrial sector.

Figure 4: Distribution of agro-food biotech firms among European countries

![Distribution of agro-food biotech firms among European countries](image)

More differences become obvious if we compare the size distribution of agro-food biotech firms between the countries (figure 5). Of those countries with a strong agro-food biotech sector, in the Netherlands and Greece mainly the larger firms with more than 100 employees dominate the scene. In France on the other hand, more than 60% of the agro-food biotech firms belong to the very small types with less than 20 employees. Spain exhibits a different picture where the medium-sized and larger firms seem to be present in comparable numbers. Among the countries with the less developed sector, Ireland is interesting because it homes the highest share of all countries of very small firms. This seems to indicate that the sector has started development rather recently. In Germany the firms are distributed rather equally among the four size classes.
3.3 The finance/industrial development network

Most countries in the EU have established specific policies to support industrial innovation. Sometimes these policies focus on biotechnology in general, but Greece, Austria and the Netherlands (until the end of the 1990s) lack any specific focus on biotechnology. In the latter country initiatives were put into place to promote the creation of new start-up companies from 2000. Greek industrial policy is mainly connected to technology transfer initiatives. Since 1998 industrial policy in Austria focuses on the commercialisation of results of public sector research, the promotion of knowledge transfer between public and private research as well as the creation of start-up companies (Senker et al., 2001).

In the other countries industrial policy is more specifically dedicated to biotechnology. In Ireland the transfer of research results to existing biotech companies or new start-up firms is supported. German industrial policy tries to encourage firms to adopt new technologies and to raise industrial awareness concerning biotechnology. In addition, the founding of high-tech companies is supported by specific credit programmes. Furthermore, application-oriented research projects are financed by funds of the Association of the Industrial Research Organisations. French industrial policy provides tax credits for companies
conducting in-house research (Senker et al., 2001). In the UK a wide range of different programmes exist to promote and fund industry-university projects as well as to encourage the creation of new start-up firms. In Spain joint research projects by firms and public research organisations as well as development projects or activities aiming to adopt new technologies in companies are funded by specific programmes. In addition, there are credit programmes to support the creation of new companies (Senker et al., 2001).

Although availability of venture capital for biotechnology firms has increased in the last years in the EU (excluding an actual decline in recent 2 years) much of the European investment in agro-food biotechnology research comes from public sources (e.g. European Commission, member stages, regions), but not from private investments. In addition to a still low availability of venture capital in some member states of the EU (e.g. Austria, Greece) agro-food biotechnology companies have not generated enthusiasm within the investment community. Compared to other biotechnology sectors agro-food biotechnology is regarded as high-risk business with very uncertain future market perspectives (Crowther et al., 1999) and limited gross potential. Therefore, in particular agro-food biotechnology SMEs face significant difficulties to finance their business activities. This situation is not only true since the recent collapse of new high-tech market segments of European stock exchanges in 2001 and 2002.

Compared to Spain, Greece, Austria and Ireland where there is a low availability of venture capital in general and all types of biotechnology companies face specific difficulties to find in particular „early stage“ or seed venture capital, the general availability of venture capital is much higher in the United Kingdom, Germany, France and the Netherlands. In particular the United Kingdom has one of the most favourable legal and fiscal environments for private equity in the EU, providing the venture capital firms with a number of exit opportunities in specific segments of the stock exchange. In Germany and the Netherlands the venture capital market is well developed and several investment firms have specialised at least partly in biotechnology investment. However, many applications of venture capital in agro-food biotechnology companies fail because start-up firms lack either the management capabilities demanded by venture capital firms (Menrad et al., 1999) or do not fulfil their high growth perspectives. Also in France a rapid growth of venture capital firms was observed in recent years which mostly invest in companies in the health sector. All these four countries have established specific segments at the stock markets in order to list high-tech companies and provide venture capital firms and other owners of start-up companies with specific exit opportunities. However, only very few agro-food biotechnology companies have been listed on European stock markets in recent years. Given the collapse of these high-tech market segments since 2000, it can be assumed that the private funding possibilities in particular for agro-food biotechnology companies most probably will not improve in the coming years in the EU.
Agro-food biotechnology products are mainly targeted to the markets of seeds, pesticides and other agro-chemicals, veterinary products as well as to the food market in general. Most of these markets represent large volume markets which are often separated in different segments. The agricultural commercial markets for seed and planting material which will be the first target for GMOs range from 60 million € in Ireland to 1,37 billion € in France (table 1). The domestic food markets in the analysed countries have a considerably higher market volume and range from around 8 billion € in Austria (Tradepartner, 2002) to 165 billion € in Germany (BMELF, 2000). In general, the markets of seeds, pesticides or food products are not specifically regulated in the EU. However, in each country and on the European level specific agencies control field trials and are concerned with the impacts of these products on health, the environment and food security.

Table 1: Domestic markets for seed in the analysed countries (billion €) in 2000

<table>
<thead>
<tr>
<th>Country</th>
<th>Market value (billion €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>0.17</td>
</tr>
<tr>
<td>France</td>
<td>1.37</td>
</tr>
<tr>
<td>Greece</td>
<td>0.14</td>
</tr>
<tr>
<td>Germany</td>
<td>1.0</td>
</tr>
<tr>
<td>Ireland</td>
<td>0.06</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>0.3</td>
</tr>
<tr>
<td>Spain</td>
<td>0.3</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Source: ASSINSEL, 2002

Public attitudes, regulatory aspects as well as the reactions of the food retail companies and food processing companies have a major impact on a potential demand for GM crops and food in the EU. Critical NGOs have played an important role in widening the debate about the use of GMOs in the agro-food sector and their views have been widely disseminated by the media in recent years. As a result negative public attitudes to GM crops and foods are now widespread in the EU although there are differences between the single member states (Gaskell et al., 2000). In Austria, Germany, Greece and the UK the public has a very negative attitude to GM crops and ingredients in food as well as very critical citizens and consumer associations which have taken an active part in the public debate in the last years. Food retailers which are highly concentrated in Austria, Germany and the United Kingdom have responded to these attitudes and removed GM ingredients from their products (Senker et al., 2001). In Greece, food retailers and
manufacturers have adopted the same position, while in Austria additional opposition came from the family-run farm sector.

In France, the Netherlands and Spain public opposition to GM crops and food was relatively moderate compared to the other analysed countries. In France media interest in the GM debate has increased since 1997 and a growing distrust by the public can be observed for GMOs. As shown in several studies, the Dutch public is more knowledgeable about biotechnology than the population in other European countries (e.g. European Commission, 1997). Interestingly, the Dutch attitudes towards biotechnology have not changed significantly during the 1990s, but the public is well informed and understands both the positive and negative aspects of this technology. Although the Dutch government tries to ensure the freedom of choice of consumers with respect to GM products, the Dutch population remains also sceptical about applications of genetic engineering to food. Compared to the other countries there is relatively less public opposition to GM food and crops in Spain. The same relates to the Irish public although GM food does not seem to attract high public support (Senker et al., 2001).

Concerning the regulation of the use of genetic engineering in the agro-food sector national, European and international regulation have a certain relevance. The highest regulation competency in this field has the EU which partly determines the framework for national regulations as well. During the 1990s the use of genetic engineering in the agro-food sector in the EU was mainly regulated by directives 90/219 and 90/220 on the contained use and deliberate release of genetically modified organisms as well as regulation 258/97/EC (Novel Food Regulation). In the last three years the EU Commission has taken additional efforts to widen and differentiate these regulations.

The European regulatory framework related to agro-food biotechnology played an important, in the views of many scientists largely negative role for the development of GMOs in the EU in the last decade. During this time period increased regulatory oversight in agro-food biotechnology coincided with growing negative public opinion and diminished trust in public authorities and regulatory agencies (Senker et al., 2001). In this context in particular the changing regulatory environment has been criticised by industry as well as the practical handling of existing regulations as being too slow, bureaucratic and causing high costs. During the interviews politics was criticised for not taking clear decisions regarding agro-food biotechnology and periodically intervening in regulatory processes. Due to their limited financial and personnel resources, in particular agro-food biotechnology SMEs face specific difficulties in the current regulatory environment of uncertainty in the EU.

The application for notification of field trials with GMOs under part B of directive 90/220/EEC gives information on the extent of field trials which have
been carried out in the different member countries of the EU since 1991. The result of such an analysis is shown in table 1. Around 30% of all notification on field trials with GMOs have been conducted in France, followed by Italy and the United Kingdom, in which 16% or around 12% of all notifications have been performed (table 2). In the other countries under consideration, in Spain and the Netherlands, a significant number of field trials have been carried out as well, while in Germany only 115 notifications for field trials were reported (table 2). In Austria, Ireland and Greece a neglectable number of field trials with GMOs was carried out during the 1990s.

Table 2: Notifications of field trials with GMOs in different member states of the EU from 1991 to 2002

<table>
<thead>
<tr>
<th>Memberstate</th>
<th>Number of field trials</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>501</td>
<td>29.7</td>
</tr>
<tr>
<td>Italy</td>
<td>272</td>
<td>16.1</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>209</td>
<td>12.4</td>
</tr>
<tr>
<td>Spain</td>
<td>180</td>
<td>10.7</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>133</td>
<td>7.9</td>
</tr>
<tr>
<td>Belgium</td>
<td>119</td>
<td>7.1</td>
</tr>
<tr>
<td>Germany</td>
<td>115</td>
<td>6.8</td>
</tr>
<tr>
<td>Sweden</td>
<td>62</td>
<td>3.7</td>
</tr>
<tr>
<td>Denmark</td>
<td>39</td>
<td>2.3</td>
</tr>
<tr>
<td>Greece</td>
<td>19</td>
<td>1.1</td>
</tr>
<tr>
<td>Finland</td>
<td>18</td>
<td>1.1</td>
</tr>
<tr>
<td>Portugal</td>
<td>12</td>
<td>0.7</td>
</tr>
<tr>
<td>Ireland</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td>Austria</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td>Total</td>
<td>1,686</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Calculations of Fraunhofer ISI based on ICHP 2002

4. Conclusions and policy implications

The development of agro-food biotechnology in the EU faces considerable constraints mainly related to a high uncertainty in the regulatory framework as well as the practical handling of the existing regulations, very uncertain market perspectives due to low consumer acceptance of GM crops and ingredients in food as well as lack of private financing opportunities for start-up agro-food biotechnology companies.
The countries that seem to have the best prerequisites to further develop their competencies in the agro-food biotechnology sector are France and the Netherlands based on their science base, multinational companies as backbone of industrial activities, a relatively good financing environment as well as moderate public opposition to GMOs. Germany has a high number of domestic agro-chemical and seed multinationals as well as a large number of scientific institutions on competitive level active in agro-food biotechnology. Although the government tries to support commercial exploitation of biotechnology in general, future perspectives of companies in the agro-food biotechnology field are impeded by the low consumer acceptance of GM crops and food as well as corresponding reactions of food manufacturing and food retail companies which try to avoid GM ingredients in their products or shelves. Spain's fast growing science base and moderate public opposition to GMOs (table 3) are specific assets to further develop agro-food biotechnology in this country, which is however slowed down by the low private investments in R&D as well as a lack of venture capital to support the establishment of start-up companies in this field. The situation in the UK is characterised by a strong science base in agro-food biotechnology, as well as a high availability of venture capital funds and a national policy which tries to commercialise the existing scientific knowledge. However, strong public opposition to GMOs and GM food in particular since 1998 has resulted in a relatively low number of newly established start-up companies in this country (table 3). Austria and Greece face specific difficulties in almost all areas which influence innovation activities in agro-food biotechnology (table 3). In Ireland commercial exploitation of agro-food biotechnology is mainly impeded by the weak industrial basis as well as a limited science base (table 3).

Table 3: Overview on influential factors for innovation activities in agro-food biotechnology in different member countries of the EU

<table>
<thead>
<tr>
<th>Country</th>
<th>Knowledge/skills</th>
<th>Industry/supply</th>
<th>Finance/industrial development</th>
<th>Demand/social acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>France</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Greece</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Germany</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Ireland</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Spain</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

+: positive; 0: neutral; -: negative

Source: Fraunhofer ISI, 2002
The findings of the study reveal significant differences in the innovation system in agro-food biotechnology between the eight EU countries studied. The great differences between these countries suggest that each country has its own pattern of innovation in agro-food biotechnology. The results of the study seem to indicate as well that countries with large home markets appear to have greater abilities than smaller ones to exploit the development of new markets for emerging technologies. The nature of demand and market seem to play a significant role in explaining different patterns of innovation activities by different countries (Senker et al., 2001). In agro-food biotechnology the potential demand in the EU was negatively affected by a combination of public opposition to GMOs, media coverage, the response of food manufacturers and retailers and high regulatory uncertainty and led to relatively low innovation activities by firms in the last five years. All in all, it can be concluded that national factors have a high influence on commercial exploitation of agro-food biotechnology in the EU which underlines the central role of national or regional innovation policies.

As the examples of Germany and the UK, where a very favourable science base is not exploited commercially, indicate there is an increasing need for taking a systemic perspective of the innovation process when designing and implementing research, development, technology and innovation (RDTI) policies. It is not sufficient to focus policy support only onto individual subnetwork of the whole system (see figure 1). Rather integrative policy approaches are called for which combine different policy functions to a more systemic policy concept.

5. Literature


Bijker, W. E., Hughes, T. and Pinch, T. J. (Editors), 1987, The social construction of technological systems: New directions in the sociology and history of technology (The MIT Press, Cambridge (MA)).


Cooke, P. et al., 1996, Regional innovation systems: concepts, analysis and typology (Brussels).


Farina, C., Preissl, B., 2000, Research and technology organisations in National Systems of Innovation, DIW Discussion paper, No. 221.


Freeman, C., Soete, L., (Editors), 1997, The economics of industrial innovation. 3rd edition (Pinter, London).


Mayntz, R., Hughes, T., 1988, The development of large technical systems (Campus Verlag, Frankfurt/Main).


Ropohl, G., (Editor), 1998, Wie die Technik zur Vernunft kommt (Fakultas, Amsterdam).

Saxenian, A., 1994, Regional advantage. Culture and competition in Silicon Valley and route 128 (Harvard University Press, Cambridge (MA)).
