FINAL REPORT

PITA Project: Policy Influences on Technology for Agriculture: Chemicals, Biotechnology and Seeds

Final Report

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List of Abbreviations

CAP	Common Agricultural Policy
EU	European Union
FQPA	Food Quality Protection Act
GM	Genetically Modified
GMOs	Genetically Modified Organisms
ICM	Integrated Crop Management
IPM	Integrated Pest Management
IPR	Intellectual Property Rights
LEAF	Linking Environment and Farming
LMO	Living Modified Organism
MNC	Multinational Company
NGOs	Non-Governmental Organisations
OECD	Organisation for Economic Cooperation and Development
PP	Precautionary Principle
PPP	Plant Protection Product
PRSEs	Public Sector Research Establishments
R&D	Research and Development
SMEs	Small and Medium Enterprises
WTO	World Trade Organisation

Abstract

Technological innovation in the agrochemicals, biotechnology and seeds industries has the potential to deliver more socially and environmentally sustainable farming systems and to improve the quality of life. However, although a range of European policies could contribute to these outcomes, in practice they often counteract one another. The PITA project conducted an integrated analysis of policies and market-related factors; investigated their impact on the strategies and decision making of companies (MNCs and SMEs) and public sector research establishments (PSREs); and considered the implications of these decisions for employment, competitiveness and environmental benefits in Europe.

The research coincided with a period of rapid restructuring of the industries as well as periods of crisis and rapid evolution in the policy, regulatory and public arenas. The traditional evolutionary patterns in the agrochemicals and seeds industries are being overtaken by a new agro-biotechnology trajectory, bringing together the two sectors with their different traditions, cultures, knowledge bases, profit margins, and regulatory regimes, and the process is creating serious tensions.

The 14 large agro-biotechnology companies studied were in various stages of evolution along the new trajectory, from Monsanto, an early adopter, to BASF and Bayer who were late starters. An important strategic change in many companies was a shift from individual products to the whole crop as a focus of innovation, but companies varied in their approach to implementing the new strategies at R&D and market levels.

The remaining large independent seed companies, if they choose to develop GM crops, are expected to find it difficult to compete with the whole crop strategies of the agro-biotechnology MNCs. For those who choose to use biotechnology only in the development of traditional crops, the long term outcome will depend on the eventual acceptability of GM crops to European consumers.

European agro-biotechnology MNCs are usually strong in Europe and the USA, and hold a similar share of the Latin American market to US companies which are much stronger in North America than in Europe. European companies are also more sensitive to European political and regulatory cultures, including the precautionary principle and the more active stakeholder approach demanded by European citizens.

Public policies in many cases have a subtle and indirect influence on companies' product development strategies; they are not the main drivers of strategic thinking. The CAP and trade liberalisation policies operate through market mechanisms and are seen as relatively predictable; inducements to convert to organic and integrated crop management (ICM) systems are so far having only a marginal impact on strategies. Environmental signals and precautionary regulation are seen by some companies as hard to manage, although few are arguing against them. The greatest regulatory concern was the uncertainty surrounding the risk regulation of genetically modified (GM) crops. However, the length of the product development cycle gives companies some protection against short-term uncertainty and in the meantime they are concentrating GM crop developments on markets outside Europe.

The issue of stakeholder values has recently become an important dimension of management. Some companies see farmers as their primary client; others accept that food processors and retailers are increasingly important actors and that consumers and public opinion exert a major influence through them. Many companies also take direct account of public attitudes and find the resistance to GM products a source of extreme uncertainty.

The evolution of the agro-biotechnology trajectory is heavily influenced by the policy issues addressed by PITA, leading to the following strategic lines: to implement whole crop strategies by ensuring a strong base in agrochemicals and a viable germoplasm base; to contribute to sustainable farming systems by developing cleaner pesticides, supporting ICM and by incorporating GM products; and by regaining customer confidence via an agreed European regulatory system and the marketing of GM products clear consumer benefits.

PSREs are struggling with the tension between their public and private roles: contributing to national economic performance by increasing links with industry, and using their knowledge to improve risk assessment and regulation in the public interest. This tension limits their role in protecting the public interest and there is a need to reinforce their independent role.

SMEs are more vulnerable to unpredictable constraints than MNCs and are vulnerable to takeover if they become successful. One emerging trend is the increasing use of specialist research units for activities such as combinatorial chemistry and robotic systems for high-throughput pesticide screening.

There are approximately 50,000 direct jobs in agro-biotechnology in the EU, and most employment effects of the new technology will be indirect throughout the food chain. Second and third generation GM products have the greatest potential to increase employment, but the spate of mergers among MNCs will probably more than counteract such gains.

New policy developments in Europe and the USA are being associated with more insistent calls for integrated approaches to policy analysis accompanied by greater openness to stakeholder participation in decision making. Our research emphasises the need for better integration of all those involved. Most policy makers have expertise in only a narrow area of the policy spectrum and mechanisms are needed to help them to envisage and respond constructively to wider policy interactions and the scope for synergies and antagonisms. PITA has identified some of these potential synergies and antagonistic effects and suggested some points of leverage for policy intervention.

1. Executive Summary

Background and objectives

Technological innovation in the agrochemical, biotechnology and seeds industries and in associated public sector research establishments (PSREs) has the potential to deliver more socially and environmentally sustainable farming systems and to improve the quality of life of citizens in Europe. This is particularly true of farms on the most fertile land. However, although policies developed in different areas may all aim to improve the quality of life, in practice, in their influence on company and PSRE strategies, they frequently counteract one another and may attenuate the desired effect.

The PITA project developed an integrated analysis of policies and market-related factors relevant to the agrochemical, biotechnology and seeds sectors. Its overall aim was to contribute to the development of sustainable industrial and farming systems and an improved quality of life by encouraging the development and uptake of 'cleaner' technology for intensive agriculture. Its objectives were:

1. to develop an integrated analysis of policy, regulatory and market-related factors relevant to technological innovation in the agrochemical, biotechnology and seeds sectors, to study their interactions and to develop hypotheses about their impact on strategic decision making in industry and PSREs;
2. to study the influence of these factors on innovation strategies in the agrochemical, biotechnology and seeds industries and PSREs, their impact on strategic-level decisions about product development, levels of investment and location of investment; and
3. to study the outcomes of industry decisions , their effects on employment and international competitiveness, and the potential of the products developed to deliver environmental benefits.

We also considered the interactions among the strategies of European based multinational companies (MNCs) and others, particularly those based in the USA.

The researchers involved in the PITA project accurately predicted that this area of technological innovation was going through a very interesting phase that would amply reward interdisciplinary socio-economic research at a European level. However we could not have predicted the extent of the disruption that would emerge over the period of the project, in the external operating environment of the policy makers and companies we were studying and also internally, involving periods of crisis and sometimes rapid evolution in the policy arena and major mergers and de-mergers among many of the companies studied.

Methodology

The three phases of the PITA project were based on the three objectives, the methodology differing for each. For objective 1, a series of reports were prepared on the policy and regulatory background in six countries (Denmark, France, Germany, Netherlands, Spain and the UK), together with overview reports on the EU policy and regulatory background, on public opinion and attitudes, on food chain influences on innovation, and an integrated policy analysis of objective 1 issues. Each of these reports was based on reviews of literature, including documentation from policy makers and institutions. Reviews were supplemented with interviews with more than thirty policy makers. Policies were categorised as those:

- to stimulate science, technology and innovation in industries;
- to regulate industry and farming (for environmental protection, public health and safety);
- agricultural and farming support policies; and

- policies for international trade liberalisation.

For Objective 2, research involved studies of fourteen MNCs (Advanta; AgrEvo, BASF, Bayer, Cebeco, Danisco, KWS, Limagrain, Monsanto, Novartis, Pioneer, Rhone-Poulenc Agro, Seminis, and Zeneca). Together these account for seven of the top ten agrochemical companies in the world, and for seven of the top ten seed companies. Studies were also made of small and medium sized enterprises (SMEs) and of public sector research establishments (PSREs) in the six countries.

The research focus was on innovation and product development, investigating the impact of the policies identified in objective 1. For MNCs, access was gained at the highest levels in most cases and interviews usually involved more than one partner. Analysis was focused on: technological trajectories in the companies and strategic decision making on product development; corporate organisational features and how these may affect the perception of policy signals; and the relationships between company trajectories and environmental policies and other pressures.

For Objective 3, an empirical study of employment issues was undertaken, together with an extended analysis, drawing policy conclusions from all relevant components of the project and contributing to the wider research effort on integrated policy analysis.

The policy environment

Objective 1, which developed an integrated analysis of public policies and market-related factors, assessed how the policies interact, developed some hypotheses about the impact of policies on strategic decision making, and described potential interactions between policy and market-related factors in influencing innovation. The major hypotheses, which were used for detailed research in Objectives 2 and 3 of the PITA project, were that:

(i) given the various constraints on SMEs commercialising their own products, MNCs may often reap the benefits of public policies to support SMEs;

(ii) reduced government funding to PSREs may lead to increased focus on the needs of private clients and decreased focus on their ‘public interest’ functions;

(iii) industry innovation strategies may increasingly focus on integrated crop management (ICM) compatible products, given the mix of public policies to promote and regulate towards that trajectory;

(iv) more stringent pesticide regulation, together with public support to promote integrated crop management, may lead plant breeders to develop varieties with better plant and disease resistance;

(v) higher development costs, CAP price support reductions, and increased regulation may lead to increased concentration in the industry and thus to decreases in innovative capacity;

(vi) if regulation remains uncertain it may lower biotechnology innovation in the seed industry. Conversely, if regulatory changes improve public acceptability, then innovation may be increased.

Although these and other hypotheses framed our research for objectives 2 and 3, the research outcomes have produced richer, even if sometimes contradictory conclusions.

MNC innovation strategies

A focus on technology strategies and trajectories allowed us, in our detailed study of fourteen major multinational companies, to consider the drivers that influence innovation from the perspectives of the companies. Relevant drivers include: the dynamics of the industry sectors including their cost structure; the organisational dynamics of each company, including their technology trajectories; the changing knowledge base, e.g. developments in biotechnology, life sciences and integrated crop protection; and the policy environment. The policy environment and a range of other factors will differ from one part of the world to another, so that companies based in Europe may behave differently from those based in North America. However, successful MNCs will balance their strategies and the timing of trajectories to cope with global variations in the policy environment.

Interactions between multinational agrochemical companies have been dominated by a series of waves of take-overs and mergers since the late 1970s as the sector has become more mature. This process has intensified recently and has been complicated, and partly stimulated, by the introduction of new areas of knowledge from biotechnology bringing agrochemical companies into closer contact with seed companies with their very different cultures, regulatory environments, markets and profit margins. The agrochemical industry was relatively concentrated at the beginning of the PITA project. During the period of the PITA project the top ten companies became seven, including four with a turnover of more than US$ 3 billion (Syngenta, Monsanto, Aventis, and BASF (with Cyanamid).

Companies in the seeds industry are smaller in terms of turnover than those in agrochemicals. The PITA project studied seven of the top ten, including three (Monsanto, Novartis and Advanta) that are owned or partially owned by agrochemical companies and one (Pioneer) that was taken over by DuPont during the period of the project.

In the mid-1980s a new technological trajectory emerged for the agrochemical and seeds industries based on biotechnology. Public and private finance combined to create one of the most sustained and costly examples of ‘technology push’ ever experienced. In pharmaceuticals this was matched by a strong market pull but in the agro-biotechnology area market demand has been problematic, at least in Europe.

The direction and strength of trajectories are influenced partly by the structure and dynamics of the industry itself and a range of other factors then comes into effect. In the agrochemical industry these include the availability and effectiveness of patent protection, the nature and direction of the regulatory regime and the breadth and depth of the knowledge base. In the seed sector, on the other hand, varieties are protected by breeders rights, regulatory regimes are weaker, and the knowledge base is dominated by plant breeding which is an integrative field at the frontier of genetics, pathology, agronomy and statistics. The new agro-biotechnology trajectory is bringing together these two industry sectors with their different traditions, cultures and knowledge bases, and different modes of interaction with the regulatory environment and the process is creating serious strains in both sectors.

Evolution of the industries

As the agrochemicals industry has evolved, the easy crop/pest targets for pesticides have been increasingly covered by effective chemicals and markets, at least in the developed world have become ‘saturated’. Thus, in most cases, a new product can only gain a market share by knocking out existing products. If existing products have already outlived their period of patent protection, and their price has fallen, it will be much more difficult for a new, expensive, patented and hence potentially more profitable pesticide to gain market share.

Most companies are attempting to rationalise their existing product range, dropping those now giving a poor return, either by taking them off the market or by selling rights to another company, and developing the profit potential of those they choose to retain. At the same time, most multinational companies in our sample have been using new technology to speed up the screening process for new agrochemicals and to improve its efficiency and targeting, by: using genomics to validate targets for new pesticides, particularly based on natural products; using combinatorial chemistry to generate large numbers of new chemicals for screening; and using high throughput screening to test very large numbers of chemicals, rapidly, on a range of living targets.

These new methods are not likely to increase the numbers of new pesticides reaching the market each year but they are expected to allow companies to meet increasingly stringent regulatory requirements while still launching one major new product every one or two years.

The seed industry aims to develop new crop varieties with innovative attributes for which farmers will be prepared to pay. The history of the industry, the techniques used in innovation, the company structure and organisation and the nature of the market combine to make this a very different industry from agrochemicals.

The success of seed companies is based on the quality of their germplasm and this characteristic is often very region specific. This feature of the sector differs to some extent from one crop to another, for example sugar beet is more adaptable to a range of conditions than maize but in general new varieties need to be evaluated in the region where they are to be marketed from an early stage of research. Centralisation of R&D facilities has not proceeded in the seeds sector to the same extent as in the agrochemicals sector. Seeds have also traditionally been a lower value-added sector than agrochemicals. Innovation through the development of new varieties was less expensive than for pesticides but rewards to the innovator were more than proportionally less. Thus the seeds sector, although a thriving component of food production systems, has been less lucrative than agrochemicals.

All the large independent seed companies in our sample were using biotechnology techniques (molecular markers and cell technologies) to speed development of new varieties, to improve the targeting of specific traits and to enhance research capacity. The use of biotechnology, beyond the above set of R&D techniques, to develop GM crops, generally has to be done in association with a multinational agro-biotechnology company. This strategy increases the costs, opportunities and threats for seed companies for the following reasons:

(i) The seed company has to bear the cost of introduction of the genetic event in its variety and bear the cost of managing a larger range of products;

(ii) GM crops create opportunities for seed companies by capturing part of the pesticide business and extending the volume of the seed market. However, this extension in the seeds market has to be shared with the agro-biotechnology company;

(iii) One threat is that the agro-biotechnology company may give an exclusive license to a seed sector competitor. Seed companies have two possible strategies : (i) to group their seed/biotechnology business to act as a ‘central buyer’ of licenses to increase their bargaining power (e.g. the creation of Biogemma in France and the merger of the US businesses of KWS and Limagrain); (ii) to build partnerships with biotechnology companies in order to secure access to the technology (eg the links between Advanta and Zeneca, and between Limagrain and Rhône Poulenc).

New agro-biotechnology trajectories

For all the multinational agrochemical companies in our sample, strategic planning now involves the construction of new agro-biotechnology trajectories - a combination of chemical and biotechnology developments with varying degrees of synergistic interaction. Companies do not envisage a future without biotechnology and in all cases this includes *products* based on biotechnology, not merely using biotechnology to develop better chemicals as outlined above. There appear to be three distinct approaches to trajectories:

- Monsanto (from a very early date) and DuPont (much more recently) have invested major amounts of shareholder funds in acquisitions – a strategy described by other companies as ‘buying the channel to market’, as well as investing heavily in building up their technology base;
- other companies (AgrEvo, Zeneca, Novartis, Rhocircumflexne Poulenc, Dow) are trying to capture value in a different way – they have invested a great deal of money in the technology and have made some acquisitions to give them a reasonable ‘route to market’ base, but not as far downstream as Monsanto and DuPont;
- BASF and Bayer are late starters with different strategies for patents, technology and route to market, looking for benefits from their agrochemical businesses to help them to buy into biotechnology, by-passing the earlier innovation phase of other companies.

The development of the first generation of GM crops, concentrating on input traits such as herbicide, insect pest and disease resistance, has been based on relatively simple technology which had been the subject of scientific investigation for a considerable time and could be implemented fairly rapidly. However, companies have not yet made much money from this technology and they see the next generation of GM crop technology as being much more difficult to achieve.

Characteristic strands of innovation for second generation GM crop products now under development include:

- quality traits such as flavour enhancement;
- better processing and feed quality, including animal feed crops tailored to the nutritional requirements of different species;
- output agronomic traits;
- improved nutrition in crops such as vegetables and rice (e.g. rice with additional vitamin A and iron, a Brussels sprout with high vitamin C content or traits that would lessen the incidence of heart disease), often described as 'functional foods' or 'nutraceuticals';

A potential third generation of GM innovations, predicted within 10-15 years and involving a different type of chemical/biotechnology synergy, will see plants being used as factories to develop a wide range of chemicals, including pharmaceuticals and bulk chemicals.

Industry managers generally agree that the input traits present in first generation GM crops have been attractive to farmers but have provided few benefits for consumers.This is widely accepted by industry as one cause of the widespread rejection of GM crops by European consumers. The output traits now being developed in second generation products are therefore expected to be much more attractive to consumers and hence to remove the stigma attached to GM crops.

The idea that some of the new GM-based output traits in crops would enhance the value of the crop, thus increasing the demand, either for crop protection chemicals or for protective GM-based input traits, is another example of a synergistic interaction between biotechnology and chemicals at the market stage but achieving the value-added requires strategic planning for the whole value chain from the early discovery stages.

Agro-biotechnology industry managers confirmed that the concept of life science synergies has played an important part in their strategic planning. Early interpretations of the term 'life science' assumed that, by using biotechnology to gain a better understanding of the functioning of cells across a wide spectrum of species, there would be useful cross-fertilisation of ideas between the development of new drugs and of new crop protection products for agriculture.

The vision in these cases was one of synergy at 'discovery' level, where a better understanding of genomics and cell processes, made possible by fundamental knowledge gained in the life sciences can lead to new drugs, new pesticides, GM crops and genetic treatments for disease. These assumptions were accepted until recently without much questioning, partly to justify the continued retention within the same multinational company of two sectors with markedly different profit potentials, pharmaceuticals and agrochemicals. However, the original conception of a life science sector is now being reinterpreted.

The synergy worked well where both partners are interested in sources of *chemical* novelty, but not in the *gene* area. Functional genomics, as a platform technology, can help both sides invent novel and profitable chemicals but unlike pharmaceuticals, in the agro-biotechnology sector there are also major commercial opportunities in the creation of GM crops. The large scale marketing of genetically modified organisms is not a significant factor in the strategies of pharmaceutical companies. Although experience in the USA and other countries has indicated that GM crop development is potentially very profitable, the negative public reaction in Europe has created potential conflicts of interest between the two industry sectors.

Over a 20 year timescale useful synergies between pharmaceutical and agricultural areas of biotechnology may again emerge, for example medicinal benefits and other health-related output traits from crop plants. However, by the time such synergies do emerge managers expected that there would no longer be a link between the agrochemical and pharmaceutical divisions of companies.

Companies were aware at an early stage that the new trajectory would be based on synergies between chemistry and biology. However, for a variety of reasons, intimate collaboration between biotechnology and agrochemicals is only just beginning to materialise after about 15 years. One important factor has been the need to change organisational cultures among staff who were largely trained as chemists, not biologists. As agrochemical companies began to link up with the seeds sector, managers also had some misconceptions about the nature of the seeds business and the future of agrochemicals and biotechnology as joint initiatives.

The demise of the pharmaceutical/agrochemical synergy in the evolution of the life science trajectory has focused more attention on the underlying synergy between chemicals and biotechnology and on the need for new and different patterns of alliance among large and small companies. In discussing the relationship between agro-biotechnology and pharmaceutical divisions several companies noted that, beyond the early discovery stage, there were few useful synergies between the two. More natural partners in developing routes to capture value from the new technology were seen to be multinational food processing and distribution companies. The changed pattern of development within the industry involving stronger linkages between agro-biotechnology divisions of different companies and weakening of links between agro-biotechnology divisions and their pharmaceutical counterparts, was thus generally seen as a positive development, offering opportunities to cultivate more useful channels to market for the new products.

With the shift of power from production to consumption, the agrifood chain is thus experiencing a gradual shift from mass production to dedicated production. Mass production is not over but there is a growing market for food that is produced according to specific quality requirements. Such changes may constitute major opportunities for agri-business firms, some of which have developed "from seed to store" innovation strategies.

The new focus of agro-biotechnology MNCs on the crop as the basis of their strategic planning creates major challenges for purely seed-based companies. SMEs can probably continue to exist on a niche market basis but the larger seed companies are unlikely to find large enough slots in the market to compete with MNCs and their new combined strategies. Depending on the outcomes for GM crops in Europe, it may be unrealistic to expect such companies to survive as large independent companies in the new agro-biotechnology trajectory.

European-ness

With the exception of Monsanto, Pioneer and Seminis, all the companies interviewed could be described as ‘European’ even although they operate on a multinational level. The sources of this European-ness probably lie in the home base of the company and the pervasive influence this has on the organisational culture.

The geographical scope of a company explains some differences in the way it perceives and interprets public policy signals which are specifically European. Our results show clearly that European agro-biotechnology MNCs are usually strong in Europe and the US and hold a similar share of the Latin American market to US companies, the US firms are much stronger in North America and less strong in Europe.

Localisation of R&D capacity also varies across companies. Where R&D facilities are concentrated in a small number of locations as for agro-biotechnology MNCs, the biotechnology R&D of companies has often been located in the US to benefit from American science and its ‘can-do’ mentality. When R&D is more widely distributed, as for seed companies, it is overall *decision making* which is concentrated.

European companies are thus more dependent on the European context and are also more sensitive to European political and regulatory cultures, including the precautionary principle (PP) and the more active stakeholder approach demanded by European citizens.

US companies take a US-based reference point for agricultural policies. The lack of understanding of, and lack of attention to, the formation of European public policies may explain the gap which has appeared since 1999 between US-based and European companies in this sector. For example, many European companies openly blame Monsanto for the public opinion backlash against GM crops in Europe. Monsanto now aims to understand European cultures better in order to "decrease hostility towards the company" and to obtain a "workable risk regulation policy".

Policy influences on company decision-making

Companies monitor their policy and regulatory environment and take account of likely short term shifts (e.g. the imposition of a pesticide tax) and long term trends (regulatory review of chemicals) in decision making for new products. Policy and regulatory changes can close off some business or technology options and can open up new ones. Forecasting in this area is only now becoming an important component of company strategies. This change has been driven, not by public policy or regulatory initiatives, but by negative consumer attitudes backed up by organised boycotting of the products of intensive agriculture, a development which could be seen as a new *ad hoc* instrument of global governance.

Policy impacts on markets

The agrochemical industry has in the past become adept at managing technological and market uncertainties. However, when turbulence occurs simultaneously in the regulatory and policy environment and in an industry's major markets along with a shifting technology trajectory the level of uncertainty may exceed what any company, no matter how far-sighted, can cope with.

European policies in support of innovation were directly relevant to companies' R&D programmes which rely on the availability of a good supply of well trained scientists–this is a major factor in decision making on where to locate R&D facilities. Europe was not yet seen as being problematic in this sense but there was a feeling of being fairly close to a threshold.

CAP reforms were seen as being overall framing policy instruments which are relatively predictable, impacting on industry by affecting the market for its products. Seed companies which were significantly oriented towards European markets were most sensitive to this type of policy instrument, particularly shifts in subsidy away from some crops. Such changes alter the location of production of the affected crop, lead to crop substitution, and can alter the balance of advantage among competing seed companies in a region (either within the EU or globally). CAP reform will thus affect the crops which are grown, and the intensity of production systems and hence will have an impact on the European environment. WTO negotiations are likely to reinforce the impact of CAP reform, operating on a global scale, shifting the location of production from one region to another as the reduction or removal of subsidies for crop production affects their relative advantage.

Subsidies to encourage farmers to convert to organic or ICM systems form part of these packages and could create markets for organic seeds, seeds with a stronger focus on pest and disease resistance or pesticides that are useful in IPM systems. Developments are so far having only a marginal impact on company strategies – while the markets they are creating are growing rapidly, it is from a very low baseline and companies are waiting to see how they will develop in the longer term before investing heavily.

Risk regulation

Companies are anticipating continuing pressure on pesticide use in agriculture, particularly on some older products which are perceived to cause environmental or human health problems. In both Europe and the United States, central registration systems exist in theory for pesticides, but they do not operate fully in practice in either administration. In the US, individual states often assume the right to take unilateral action and in the EU nations do still regulate on the basis of local issues.

Particularly important from the perspective of this project, both Zeneca and Novartis considered that where a product had some environmental advantages, the policy and regulatory environment was improving in both the EU and the US. Pesticide regulation was seen as having the potential to create markets for new pesticides. Attempts in the early 1990s to use regulation in this way were seen as ineffective because they did not create any incentives – regulators were trying to get greener products with no levers or rewards for industry. Novartis also commented that R&D based companies should, when they have new and better technology, replace old products. However, where older products are cheap there will be pressure from farmers to keep them on the market, and a regulatory incentive would probably be needed to encourage change and enable the company to promote it effectively.

Two regulatory instruments, one European and the other American, were mentioned specifically by several managers in the context of 'cleaner' technology:

> The EC Drinking Water Directive (80/778) was the stimulus for one of the most important filters in the early screening of pesticides. Any product which had a tendency to be mobile in soils, no matter what its other attributes, would be rejected at that point. This is regarded pragmatically by industry as part of the innovation process in that, among other things, it creates openings to replace old products that cannot meet the new standards. However, there is also some evidence that it is leading to the rejection of some chemicals with a potentially cleaner environmental profile but with a high mobility in soils
>
> The second regulatory instrument is the US Food Quality Protection Act (FQPA). This has introduced a new safety standard, reasonable certainty of no harm, that must be applied to all pesticides used on foods, plus a system to expedite the approval of safer pesticides. This 'fast track' regulatory process for products which can claim environmental or health benefits compared to the existing product range has changed the basis of competition among companies, moving from individual safety assessment to comparative risk analysis, leading to greener products rather than products directed to a specific market.

Both instruments have been criticised by industry managers for being based on precaution rather than 'sound science'. However anecdotal evidence suggests that the FQPA is more unpopular among junior than among senior managers; and more unpopular among US than among European companies. Industry opinion of the Drinking Water Directive was more uniformly critical. According to some managers it is preventing potentially useful new products from reaching the market place while the FQPA is creating the kind of regulatory incentive for 'cleaner' technology that some managers saw as desirable. The difference may lie in the fact that one discriminates among pesticides on the basis of presumed, but not proven, environmental and health benefits, while the other fails to discriminate among pesticides on the basis of presumed, but not proven, environmental and health risks. These comments are not intended to imply that either piece of legislation should be changed; they are used here as examples of different approaches to risk regulation and a demonstration of different types of impact on industry decision making. We should learn from such examples in designing future policies and regulations.

Almost unanimously the greatest regulatory concern among company managers was the uncertainty surrounding the eventual system for risk regulation of GM crops in Europe and even the date when the current impasse might be resolved. The agro-biotechnology industry has become adept at coping with complex and demanding risk regulatory systems but, as noted above, uncertainty about the regulatory system is severely inhibiting product development *in the long run*. However, the very length of the product development cycle does give companies some protection against short-term uncertainty. Strategic decisions are being made today for products that will not reach the market for at least another five years and many managers were hoping that the current regulatory problems in Europe would be resolved in that timescale. In the meantime, being multinationals, they were concentrating their efforts on markets outside Europe.

Shareholders, stakeholders and other key actors

The European problem was seen as political rather than regulatory and the solution was seen to lie mainly in recovering a favourable public opinion for the industry and its products. To achieve this, companies were advocating more effective dialogue with a wider range of stakeholders than had been the case in the past (see below) and also a stronger focus on second generation GM crop products such as functional foods and nutraceuticals that were expected to have a greater publicly perceived benefit than the first generation of GM crops.

Although there was general recognition among companies of the need for greater openness in dealings with stakeholders there were important differences among companies in the way client/customer/stakeholder issues are managed. The trend is towards a more open, multi-stakeholder approach to strategy but many companies feel uncomfortable with this, and stay more narrowly focused on the ‘farmer’ as customer and their shareholders as controller. Such differences may be partly related to differences in ownership structures, for example among companies which depend on volatile stock-market ratings (Monsanto and Zeneca) and those which have a more stable set of shareholders including industrial capital and banks (AgrEvo, BASF, Bayer, Novartis, RPA). Some companies are family owned (KWS) or farmer co-operatively controlled (Cebeco, Limagrain).

Some companies see themselves as firmly embedded in a system where farmers are the primary client. However, others accept that food processors and retailers are increasingly important actors (Novartis and AgrEvo) and many confirmed that consumers and public opinion were much more important than they had been in the past.

The issue of stakeholder (as opposed to shareholder) values has emerged recently as an important dimension of company management. Stakeholder values may impact on companies through market mechanisms (ethical consumption, boycotts), the political system or shareholder meetings (ethical funds). They are generally weak but accumulate as a result of frustration and dissatisfaction. Time lag between the communication of stakeholders’ values and response in firm behaviour may undermine company legitimacy and weaken its long term sustainability.

Sustainable development

Almost all companies in our sample have for some time used the concept of sustainability to describe their vision of the interactions between agriculture and the environment, involving both feeding a growing world population and at the same time protecting biodiversity. A recent element in this argument is the role of GM crops in reducing dependence on pesticides while further increasing crop yields. Where environmental sustainability was included in a company’s conception of sustainable development it often involved linking GM crop and pesticide strategies.

Policy interactions with life science trajectory

The evolution of the life science trajectory in the agro-biotechnology industry is heavily influenced by the policy and other issues that are the subject of the PITA project.

It would be naïve to expect companies not to aim to maximise their profit potential but one interesting outcome from the perspective of the PITA project is the extent to which companies use the dialogue of sustainability, not simply to justify their actions, but also to guide their expectations of future impacts of policy on their business areas. In developing the new agro-biotechnology trajectories, companies are thus bringing all their resources to bear on the joint resolution of the interacting problems that link the main themes of Objectives 2 and 3 of the PITA project. The kinds of strategic lines are:

> Developing whole crop strategies
>
> This concept, underlies the new approach to strategic planning already in existence in various stages of development in most of the MNCs studied. Strategies are being developed on the basis of particular crops, generally major crops traded globally as commodities, often in all the countries where they are grown. Under this strategy,

companies will offer their customers (the farmers) a package incorporating both the seed and the technology to protect the growing crop and will compete on the basis of the quality of the package, rather than on the basis of individual pesticides as in the past. There was a strong feeling from the interviews that to succeed with this strategy, companies will need to have a strong base in agrochemicals and also a viable germplasm base, either in-house or through alliances with seed companies.

Contributing to sustainable farming systems

All companies included in the sample claimed to be making a contribution to sustainability of farming systems. The whole crop strategies contributed to this, they claimed, by:

- supporting high yielding agriculture, while at the same time reducing pesticide use and developing ‘cleaner’ pesticides;
- feeding an expanding world population, at least over the next 20 years and possibly beyond. Such claims have been heavily criticised by environmental groups who note that very little of the GM technology being developed in current company strategies is directed to developing country needs;
- contributing to ICM systems, partly through the availability of ‘cleaner’ pesticides and partly by using GM technology to reduce the amount of pesticide needed for effective crop protection;
- reducing levels of pesticide use which result from the adoption of ‘cleaner’ low dose pesticides and the substitution of pesticides by GM solutions incorporated in crops.

Regaining consumer confidence in GM crops and foods.

Regulatory solutions to the problem of public acceptance of GM crops were seen to have a role in regaining customer confidence, including support for a revised European regulatory system (if it could provide the required element of certainty over a period of time) and also support for consumer choice through labelling. However the option which was expected by companies to be the most effective influence on the public was to develop products which customers will want to buy. Companies believed that one reason for the unpopularity of the first generation of GM products was that there were no apparent benefits at the consumer level. Functional foods and nutraceuticals were seen to provide the necessary element of public desirability and so were expected to change public attitudes. However there is as yet little evidence that functional foods will be the solution to the current set of problems and not the source of the next set of consumer problems.

Retaining long term viability and competitiveness for the company

The three major strands of strategic thinking outlined above were each expected to contribute to the viability and competitiveness of the companies included in the survey. The functional food component made an additional contribution to company competitiveness, if not to sustainable farming systems. By creating higher value crops in niche markets it will stimulate demand from farmers for more effective crop protection and so expand the market for new pesticides and GM crops. Thus functional foods, far from replacing the first generation GM products, may be based on building an additional set of characteristics into them.

Policy influences in seeds companies

Purely seed companies were regarded by agrochemical companies as targets for take-over or, at best, for partnerships in their search for a viable seed base. From the perspective of the seed companies themselves, they saw public policies and regulation to minimise pesticide use as signals to develop crop varieties with improved insect pest and disease resistance, either GM or non-GM. On the other hand they did not have the resources to invest on the same scale as the agro-biotechnology MNCs with their whole crop strategies.

Where seed companies had adopted GM technology, they were much more vulnerable to negative European public opinion in the short term. On the other hand, where seed companies were not involved in developing GM crops, they may be positively affected by current European public opinion which improves the market prospects for non-GM crops. Their long term prospects depend on the future direction taken by public opinion, in Europe and globally.

PSREs

PSREs are struggling with the tensions between pressures on them to contribute to national economic performance and to use their knowledge and expertise in the public interest. PSREs have been encouraged to become more responsive to the needs of industry users and governments have tried to encourage more industry support for PSREs. Public interest functions carried out by PSREs include: research and development on techniques with public rather than commercial benefits, e.g. ICM; developing and supporting risk regulatory and monitoring systems; and evaluating new technological developments from the perspective of potential risks and benefits.

The changes in the funding systems for PSREs which have directed activities more to commercial needs have led many observers to question whether PSREs can now be trusted to give impartial advice in the public interest.

The current structure and role of PSREs perhaps limits the extent to which they can contribute to discussions about the risks of new technologies. As the precautionary principle becomes more important in risk assessment in European agriculture the role of public sector research becomes more complex. Although public sector researchers have identified some potential risks, and governments have begun to involve PSREs in risk assessment, PSRE programmes have not, with few exceptions, reflected the importance of risk assessment in the debate about new technology in agriculture. This may be an indication of government ambiguity about the extent of public sector involvement in risk assessment, and also in some cases a rather narrow approach to promotion of national competitiveness and new technology. Increased private sector involvement in PSREs thus poses some problems for PSRE involvement in risk analysis at a time when trust in government monitoring of new technologies and associated risks is low.

SMEs

During the 1980’s and early 1990s, biotechnology was expected to herald a new era in agro-chemical and seed development, following the same pattern as the IT revolution, with new small firms forcing the pace of change and forging new trajectories. This might have allowed SMEs to create new markets based on more environmentally-sound biotechnology based products. However, control of the evolution of agro-biotechnology has remained firmly rooted in MNCs. Market and industry structures, lack of venture capital, high development costs and regulatory hurdles have prevented these trends from emerging. Uncertainty surrounding public attitudes to biotechnology has compounded these problems for SMEs with the result that the sector is very small indeed and many firms are struggling to survive.

A number of agro-biotechnology SMEs emerged in the late 1980s and early 1990s but few have remained independent and the rate of new start-ups declined throughout the 1990s. The recent increase again in the number of biotechnology based SMEs in Europe is probably linked to European governments promotion policies. Most of the new firms are in the pharmaceutical sector which has a different market and industry structure and regulatory regimes and also higher profit margins and provides a more favourable environment for SMEs.

In agrochemicals, the few independent SMEs are facing a major challenge to adapt their products to the new requirements of EC Directive 91/414 which increases the costs of registration of new products and may lead to withdrawal of older off-patent products. The strategy adopted by these companies is to seek new environmentally-beneficial products to be used with IPM systems and the search of niche markets to avoid competition with MNCs.

In this sense bio-pesticides offer opportunities, in niche markets and as a complement to agrochemical products.

In seeds, the challenge facing independent SMEs is the introduction of biotechnology into their core competencies. Their strategy is to concentrate on developing a few crop varieties for local markets, targeting their R&D investments on pest and disease resistant varieties in response to environmental and agricultural policies and agro-food industry demands for the reduction of pesticide usage in agriculture. Since the GM crop market remains uncertain and SMEs do not have the resources to cope with this uncertainty, most of them use traditional breeding techniques, increasingly also involving assisted breeding.

In biotechnology, SMEs mainly carry out R&D for large companies. Their strength lies in alliances and networks with PSREs (to gain access to the latest scientific advances) and with MNCs (to ensure that their products respond to market demands and to provide a buffer against uncertainty). Solutions to environmental problems are seen as a market opportunity for SMEs.

Employment

Previous studies of employment creation via agro-biotechnology are inaccurate. One data set suggests that there were 5,625 jobs in Europe in entrepreneurial agro-biotechnology firms in 1996. This is an underestimate, since only dedicated biotechnology firms with less than 500 employees are included, whereas the use of biotechnology in Europe is concentrated in large firms. Conversely, another influential study vastly overestimates employment by assuming that all employees in firms that use agro-biotechnology at any point are in biotechnology ‘dependent’ jobs. This method estimates 588,000 agro-biotechnology jobs.

There were approximately 50,000 direct jobs in agro-biotechnology in the EU in the late 1990s. Most of the employment impacts of agro-biotechnology will be due to indirect effects throughout the agro-food chain, where total employment in food processing alone is over 3 million.

Of the innovation options available to seed firms, quality traits have the greatest potential to increase employment in the agro-food chain, through an increase in value-added, the development of new markets for industrial inputs, and import substitution. The potential for seed firms to develop quality innovations is constrained by the cost of identity preservation, competitive alternatives and low switching costs for farmers, food, and industrial processors. The field test data show that there has been no increase over the past five years in the share of quality traits among crop trials suggesting that it could be at least five years before GM quality traits begin to reach European markets and affect employment. This accords with the predictions made by industry managers in interviews.

All innovation options could lead to an increase in European employment if European seed firms succeed in foreign markets, where most future growth lies. Most increases are likely to be skilled jobs in research and management since seeds are tested in their market area but the direct effect on seed firms is likely to be small. Many gains could be lost due to mergers.

Employment in the agrochemicals sector is most likely to increase through the development of chemical-crop combinations. It could also increase through the adoption of quality-enhanced seeds, which could encourage farmers to use more plant protection products to protect the higher value crops. Again job gains would be small in the short term.

Unfavourable market and regulatory conditions for GM crops in Europe could reduce the competitiveness of European seed firms and the potential for employment gains. However, the survey results show that these concerns are unfounded in the short term. These results show that European seed firms are rapidly building competencies in genetic engineering, while hedging their bets and they should be able to remain competitive in either a favourable or hostile environment towards GM crops. Interviews in companies suggested employment changes from contracting out of some high technology functions, such as bioinformatics, though such jobs would not necessarily be in Europe.

Conclusions and policy implications

Since 1997, when this project was conceived, the European policy and regulatory environment has been going through a period of extreme turbulence, particularly in the context of GM crops, with potentially major impacts on the companies we have been studying and on the European environment. At the global level the risk regulation of GM crops has been an important influence on the Millennium Round of WTO talks, and trade in GM crops and foods has become a focus for potential dispute between Europe and other regions of the world. The agricultural agenda for these talks has been shifting to include non-food concerns and multifunctionality of farming systems. However, public concerns about risk regulation have remained, including sustainability of food production systems, the increasingly rapid pace of technological innovation and the power of multinational companies to control trade in agricultural commodities.

The major policy issues contributing to these developments have been trade liberalisation, the role of the precautionary principle in risk regulation, evaluation of the environmental impact of GM crops, the involvement of a wide range of stakeholders in decision making about regulation of GM crops and the relative roles of science, ethics and values in policy and regulatory processes.

In most European countries the regulatory and policy environment for the development and marketing of GM crops has been changing in response to public concerns, pressure from environmental and consumer groups, developments in scientific understanding and evolution of industry strategies.

As indicated in the previous sections the policy environment has had a range of impacts on industry strategies and, by implication on the overall outcomes of interest – employment, international competitiveness and environmental improvement. The following are some key points to emerge from the interviews with companies and PSREs:

- Public policy influences on companies are subtle and in many cases have an indirect rather than a direct influence on product development strategies, they are not the main drivers used in company strategic thinking;
- Policy initiatives promoting innovation have become more common, expressing the desire by national governments and the EU to speed the progress of new ideas from the laboratory to the market place and hence to maintain competitiveness in a global trading environment. However, policies have had little direct impact on innovation in agro-biotechnology companies which have always been highly innovative and used to working with long development time scales;
- There is little doubt at government level about the need for, and benefits from, public support for fundamental research and for training highly qualified scientists, engineers and managers. In addition, policies to support innovation, particularly in the agro-biotechnology area, *could* lead to faster development of a range of technology options with the potential to improve the sustainability of farming systems;
- Given that regulatory systems are becoming stricter and more complex, the direction of innovation in pesticides and biotechnology to sustainable farming is likely to be dictated by MNC strategies;
- Companies do take account of public opinion and attitudes and they find the public resistance to GM products a source of extreme uncertainty. They also find it difficult to relate to pressure groups, NGOs and broad environmental coalitions. They feel they must take account of these factors but have not so far found a coherent way of doing so;
- Companies see some policy signals as clearer and easier to take on board than others, particularly those such as CAP developments and trade liberalisation signals that operate through market mechanisms, markets being one of the main foci for technology forecasting. Environmental signals and precautionary regulation are seen by some companies as hard to manage although few are arguing against them. Most MNCs are close to policy making and regulatory circles and while they may criticise some decisions and regulatory trends, they

incorporate new policy processes and adjust to them on a day-to-day basis. During the product screening process, decisions are based on regulations and directives and, other things being equal, potential products which are environmentally more sensitive will be given greater priority than less sustainable products;

- All big and most medium sized companies publicise their support for sustainable development and integrated crop management initiatives. However, at the strategic level environmental policies do not seem so prominent in decision making on new product development;
- The major factors in industry product development decision-making are market opportunities and technological innovation. New opportunities for combined agrochemical and biotechnology trajectories are leading to stronger pressures to link agrochemicals and biotechnology/seeds competencies within MNCs although all companies are in various stages of articulating this synergy between chemistry and biology;
- MNCs involved in this project face the need to invest in biotechnology R&D and to continue to invest in agrochemicals R&D at a time when the world market for pesticides (the main source of funds for investment) is relatively static or declining. These factors are leading to a spate of mergers to achieve global economies of scale and to some companies splitting off their agrochemical from their pharmaceutical divisions;
- PSREs are being expected to serve both public and private roles in these areas: contributing, as publicly funded bodies, to the development of new ideas; working with industry to facilitate their exploitation in the market place; and also working, again in a public role, with governments in support of regulatory systems, particularly for GM crops. The tensions between these various roles are placing strains on the traditional independence and impartiality of PSREs and there is a need to reinforce their independent role in risk assessment;
- Smaller companies are vulnerable to unpredictable constraints, regulations and market fluctuations than MNCs and are vulnerable to take over if they become successful. SMEs do, however, provide a significant source of employment and an effective route for the translation of new ideas from concept to market realisation. One emerging trend is the increasing use by MNCs of specialist research units (private and public), for example for specialist research on combinatorial chemistry and for development of robotic systems for high-throughput screening of pesticides;
- Innovation in the agrochemical, biotechnology and seeds sectors is likely to create some direct job opportunities in the and also major indirect opportunities throughout the agro-food chain. New quality traits introduced into GM crops are expected to have the biggest impact on indirect employment. On the other hand, competition effects among companies are likely to reduce the numbers employed in the sector as a whole.

As noted earlier, strategic decision making on the scale and location of R&D activities in these industry sectors is mainly on a global scale. Decisions taken on the basis of company competitiveness can thus have long term impacts on employment and also competitiveness at national and European levels. Company predictions that they would be forced by EU regulatory inconvenience to move their headquarters to the USA have been made for some time and have not yet been borne out. However, there has been a long term process of attrition. Many of the European MNCs have moved the location of their biotechnology discovery strategies to the USA, although mainly for reasons associated with knowledge generation rather than regulation. R&D headquarters for pesticides are generally still located in Europe but as the agro-biotechnology trajectory gets under way, with its potentially stronger links between chemicals and biotechnology strategies, and as it is progressed further down the development pipeline, there is a possibility that Europe will be sidelined. One factor which would at least delay this outcome is the spread of public opposition to GM crops to other major cropping regions of the world with corresponding delays in the evolution of the global agro-biotechnology trajectory.

GM crops have a greater potential than pesticide regulations and policies to reduce levels of pesticide use although opinions differ about the relative risks and benefits. For example, GM insect and disease resistant crops would reduce, but not eliminate, the need for pesticide applications. Herbicide resistant crops also have the potential, if treated appropriately by farmers, to improve the environmental performance of some cropping systems.

Pesticide taxes are increasingly part of the policy agenda at EU and national levels. They may be applied indiscriminately to all pesticides or selectively to pesticides regarded as most damaging to health or the environment. They are generally seen by industry and economists as inefficient and largely ineffective.

Regulatory review can stimulate innovation by removing products regarded as undesirable from the market and creating market niches for new, more environmentally sustainable products. This was seen by industry managers as a more effective method than taxes to encourage change, for example by creating markets for the newer, more benign but more expensive pesticides now in development.

In European policy circles, there appears to be a consensus emerging that GM crops have been introduced with undue haste and perhaps with insufficient attention to the need for public reassurance based on widely available evidence of safety and also public choice based on clear labelling.

The PITA project has had two major foci – analysis of strategic decision making in companies developing pesticides, GM crops and seeds and in PSREs; and an integrated policy analysis of the environment within which these companies are operating and the impact of that environment on their decisions. Recent political developments in Europe and the USA have been accompanied by more insistent calls for integrated approaches to policy analysis accompanied by greater openness to stakeholder participation in decision making. Research undertaken for this project has further emphasised the need for better integration from the perspectives of all those involved.

Demands for more integrated approaches are driven by the realisation that policies often deliver much less than is expected or intended, because of counter-productive interactions among the key actors, or because the policies arising from different sectors of the policy environment conflict with one another. On the other hand, where interactions among the actors or the policies are supportive, the desired outputs can be achieved more rapidly and at less public cost.

The comprehensive interdisciplinary policy analysis and the methods adopted for the study of company and PSRE strategies in this project have enabled us to identify some of these potential synergies and antagonistic effects for this important industrial sector and to suggest points of leverage for policy intervention. The insights gained from industry and policy makers about the reality of their interactions with one another and with the policy process have set the scene for further policy developments in other areas. Policy makers and those who react to policies usually have expertise only in a narrow area of the overall policy spectrum and mechanisms are needed to enable them to envisage and respond to wider policy interactions and the scope for policy synergies and antagonisms.

2. Background and objectives

As we noted in our proposal for this project, technological innovation in the agrochemical, biotechnology and seeds industries and in associated public sector research establishments (PSREs) has the potential to deliver more socially and environmentally sustainable farming systems and to improve the quality of life of citizens in Europe. This is particularly true of farms on the most fertile land. However, although policies developed in different areas may all aim to improve the quality of life, in practice, in their influence on company and PSRE strategies, they frequently counteract one another and may attenuate the desired effect.

Market-related factors also influence decision making in industry and PSREs, the most important for this project being the policies of food processors and distributors and also public attitudes and opinion, which often set more demanding standards than those of national governments and the EU.

The PITA project (see Figure 2.1) developed an integrated analysis of policies and market-related factors relevant to the agrochemical, biotechnology and seeds sectors. Its overall aim is to contribute to the development of sustainable industrial and farming systems and an improved quality of life by encouraging the development and uptake of 'cleaner' technology for intensive agriculture. Its objectives are:

- to develop an integrated analysis of policy, regulatory and market-related factors relevant to technological innovation in the agrochemical, biotechnology and seeds sectors, to study their interactions and to develop hypotheses about their impact on strategic decision making in industry and PSREs;
- to study the influence of these factors on innovation strategies in the agrochemical, biotechnology and seeds industries and PSREs, their impact on strategic-level decisions about product development, levels of investment and location of investment; and
- to study the outcomes of industry decisions , their effects on employment and international competitiveness, and the potential of the products developed to deliver environmental benefits.

Given the multinational nature of these industry sectors, we also considered the interactions among the strategies of European based multinational companies (MNCs) and others, particularly those based in the USA.

The researchers involved in the PITA project accurately predicted that this area of technological innovation was going through a very interesting phase that would amply reward interdisciplinary socio-economic research at a European level. However we could not have predicted the extent of the disruption that would emerge over the period of the project, in the external operating environment of the policy makers and companies we were studying and also internally, involving periods of crisis and sometimes rapid evolution in the policy arena and major mergers and de-mergers among many of the companies studied.

These factors added greatly to the interest and importance of the results of the PITA project but they also made it much more difficult than expected to organise interviews with senior policy makers and company managers and also to keep track of rapidly evolving events. We would like to record our gratitude for the high levels of co-operation we had from all those involved in the project, many of whom gave their time for interviews and for commenting on reports at times of very considerable pressure.

This Final Report cannot do justice to the rich body of information contained in the attached Annexes. It draws together the main conclusions arising from these reports in the context of the above objectives and will be one of the main routes to feed back the project outcomes to industry, policy makers and others. However, the more detailed reports would need to be consulted for a full explanation of the outcomes in each case.

The PITA project encompassed a range of different disciplinary perspectives which add to the interest and richness of the study. This Final Report integrates these contributions and adds the interdisciplinary policy analytical perspectives of the project's overall co-ordinators, covering technology trajectories, risk regulation, the policy environment for innovative technologies and public attitudes to technology.

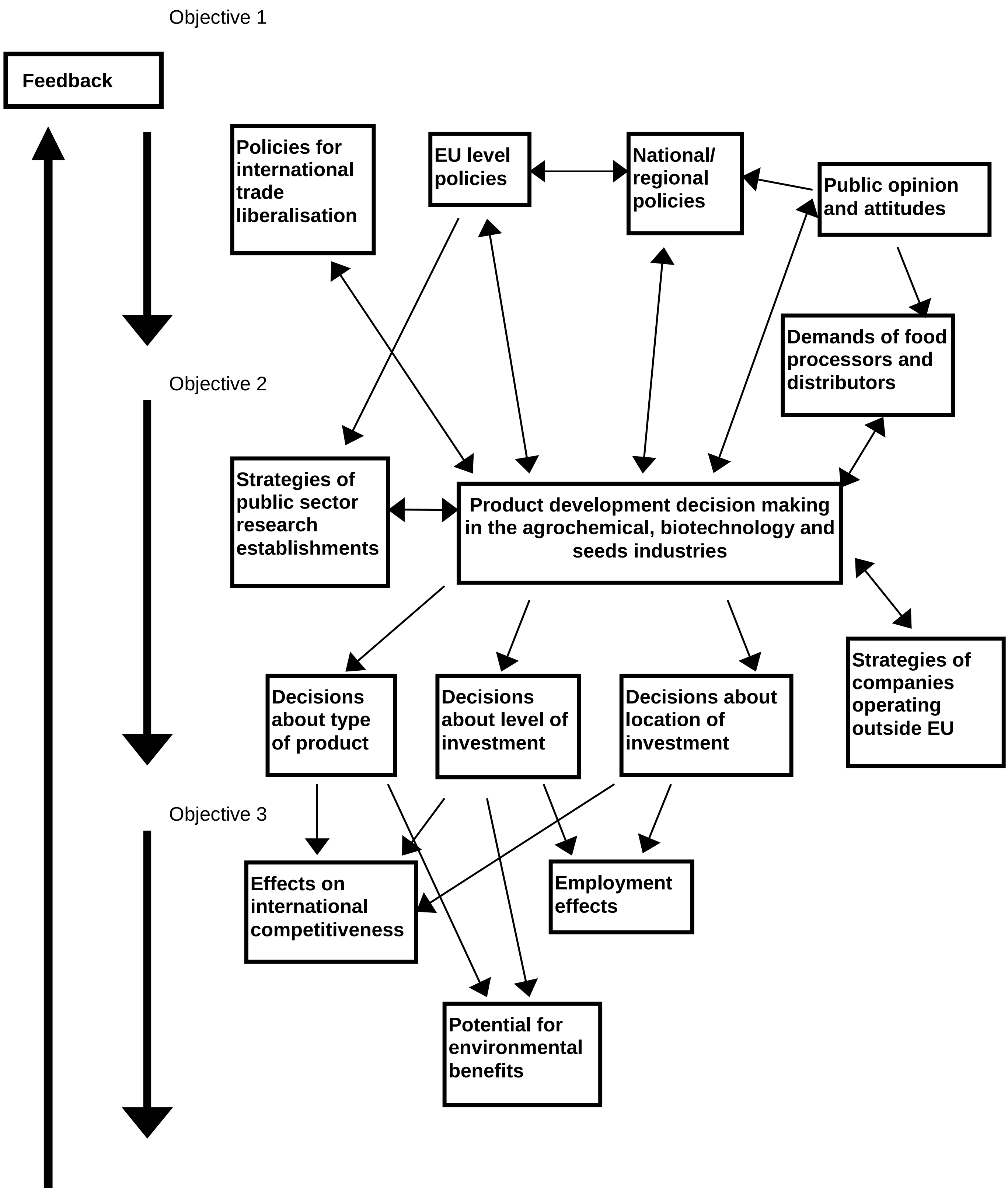

Figure 2.1 Project Structure

3. Methodology

The three phases of the PITA project were based on the objectives outlined in Figure 2.1. The methodology adopted in each case is described in the relevant reports. The tasks and outputs in each phase were as follows.

Objective 1: *to develop an integrated analysis of policies and market-related factors relevant to technological innovation in the agrochemical, biotechnology and seeds sectors, to explore their interactions and to develop hypotheses about their impact on strategic decision making in industry and PSREs*.

Outputs include:

1. a series of reports on the policy and regulatory background in each country studied (Denmark, France, Netherlands, Spain, UK). (Annexes B5-B9)
2. an overview report on the EU policy and regulatory background (Annex B3)
3. overview reports on public opinion and attitudes (Annex B4); and on food chain influences on innovation (Annex B2)
4. an additional policy overview for Germany (Annex B6)
5. an integrated policy analysis of objective 1 issues (Annex B1).

Each of these reports was based on reviews of the literature, primary and secondary, including documentation from policy makers and institutions at national and EU levels. Literature reviews were supplemented by interviews with more than thirty policy makers. The policies were categorised as follows:

- policies to stimulate science, technology and innovation in the agrochemical, seed and biotechnology industries
- policies for regulation of industry and farming (for environmental protection, public health and safety, particularly for pesticides and biotechnology)
- agricultural and farming support policies
- policies for international trade liberalisation.

Reports were also produced on public opinion and attitudes and on the impact of the policies of food processors and distributors on decision making in our target industries.

Objective 2: *to study the influence of policies and market related factors on innovation strategies in the agrochemicals, seeds and biotechnology industries and in PSREs, including their impact on decisions about product development, levels of investment and location of investment.*

Research involved:

1. studies of fourteen MNCs (Advanta; AgrEvo, BASF, Bayer, Cebeco, Danisco, KWS, Limagrain, Monsanto, Novartis, Pioneer, Rhône-Poulenc Agro, Seminis, and Zeneca). Together these account for seven of the top ten agrochemical companies in the world with around 60% of global sales, and for seven of the top ten seed companies;
2. studies of small and medium sized enterprises (SMEs) in six countries (Denmark, France, Germany, Netherlands, Spain and the UK);
3. studies of PSREs in the same countries.

The studies used agreed interview and data gathering frameworks. The research focus was on innovation and product development, investigating the impact of the policies identified in objective 1. For MNCs, access was gained at the highest levels in most cases and interviews usually involved more than one partner.

The analysis was undertaken as follows.

1. A dossier was produced for each MNC based on company literature, websites and other publicly available information. Information in the dossiers was then integrated into the company monograph along with analysis of the interview data. Each monograph included sections on: technological trajectories in the companies and strategic decision making on product development; corporate organisational features and how these may affect the perception of policy signals; and the relationships between company trajectories and environmental policies and other pressures. The monographs are published as Annexes C3-C16. A Transversal Analysis of the monographs was produced to give an overview of the multinational company analyses and to draw out main conclusions from this component of the project (Annex C1). Finally, we used the technique of cognitive mapping to provide a summary of the discourse of each MNC and to facilitate comparisons among companies (Annex C2).
2. Six national reports on SMEs were produced (Annexes D2-D7) along with a Transversal Analysis (Annex D1).
3. Similarly, six reports were produced on PSREs together with a Transversal Analysis (Annexes E1-7).

Objective 3: *to study the outcomes of the industry decisions investigated under objective 2, in their effects on employment and on international competitiveness and the potential to deliver on environmental benefits.*

Work for this objective had two main parts:

1. an empirical study of employment issues (Annex F1).
2. an extended analysis, drawing policy conclusions from all relevant components of the project and contributing to the wider research effort on integrated policy analysis (included in sections 4 to 10 of this report).

4. The policy environment and its potential impact on industry

4.1 Introduction

Technological innovation in the agrochemical, biotechnology and seeds sectors is the result of intricate interactions among markets, technologies, firm strategies, government policies and, in this case, public opinion. This section focuses on how public policies influence market and technological opportunities for the agrochemical, biotechnology and seeds industries.

The existence of a specific seed industry sector in support of agricultural production has been growing since the late 1800s. The MNCs involved in the agrochemical industry sector rose to prominence from the 1950s on and biotechnology products have emerged, first as tools for R&D and then as marketable products since the 1980s.

The products adopted by farmers, particularly those operating the most intensive farming systems, can have significant environmental impacts (positive and negative) – the choice of the crop and variety determines the cultivation pattern (e.g. time and location of sowing, irrigation requirements), and vulnerability to pests, diseases and weeds influence the use of plant protection products.

Innovation thus has the potential to improve the environmental impact of European farming systems but this will require both that industry and PSREs develop appropriate innovative products and that farmers adopt them. Both sectors (industry and agriculture) are subject to a wide range of policies and regulations designed to influence their behaviour in these contexts, but this policy environment has evolved in a piecemeal fashion and measures may have contradictory effects in different areas. Public policies can influence innovation by supporting R&D, setting environmental requirements, and stimulating particular types of farming. From an evolutionary perspective, R&D activities provide variation and farmers make up the selection environment. New crop varieties and new plant protection products will only be commercially successful if they yield benefits for the farmer. Policies can thus have both direct impacts on innovators and indirect impacts operating via the market for ‘cleaner’ technology which in turn depends on other policy influences on farmers.

A recent development has been the intrusion of a range of other influences into the previously symbiotic relationship between the agrochemical industry and farming sectors. Consumers have become more demanding and have developed effective means, even at international levels, to influence the market for farmers’ produce via the large food processors and distributors (Tait and Bruce, 2001). Over the period of the PITA project, an escalation of the negative European public response to the adoption of GM crops has caused both industry and farmers to re-assess the range of stakeholders with which they need to interact. In some cases these public responses have over-ridden government policy and regulatory positions, further complicating the operating environment for innovators.

4.2 Integrated analysis

This integrated analysis of public policies and market-related factors (see Annex B1) assesses how the relevant policies interact, develops hypotheses about the impact of policies on strategic decision making in industry and PSREs and describes the potential interactions between policy and market-related factors in influencing innovation, for example to strengthen or weaken the efficacy of individual policies. For example, seeds and pesticides are primarily developed, produced and used by private firms pursuing economic goals, the major driver being market opportunity. Public policies and regulatory initiatives affect market opportunities, by creating and/or reinforcing them, by redirecting them or by restraining them.

Integration will also focus on the geographical level of policy making and implementation, for example at national, EU and global levels.

This integrated analysis describes which policies are most influential at the various stages of the production and distribution chain, and studies the combined impact of the various policies on actors and activities. Figure 3.1 summarises the main strands in this integration process as a cognitive map

4.2.1 Science, technology and innovation (STI) policies

Diederen *et al.* (1999) describe science policy as concerned with the advancement of knowledge and technology policy as concerned with the practical application of, often scientific, knowledge for commercial and other benefit. Important technology policies in the agrochemical, biotechnology and seeds industries include intellectual property rights (IPR), support programmes for biotechnology research, and support for technology transfer to SMEs. Relevant science policies include publicly funded R&D programmes for crop protection, and the restructuring of public agricultural research. As shown on the left hand side of Figure 3.1, MNCs often reap the benefits of these public policies even though they may not be their primary targets, through having the expertise of PSREs more focused on the needs of industry and also in the sense that SMEs receive government support to develop new technology, almost invariably, in this sector, being taken over by a MNC before their products are ready for market.

Since the early 1980s biotechnology has been considered a key technology, together with information technology and new materials, for the foundation for new economic growth and globalisation of production. In the 1980s promotion of biotechnology focused on fundamental research and in the 1990s governmental programmes put more emphasis on the transfer of basic knowledge to private companies to stimulate the international competitiveness of national and European industry. Although private industry has been strongly involved in many biotechnology support programmes, both policy makers and industry managers continue to complain about the gap between public research and private R&D and the lack of collaboration.

Fundamental plant-related research for agriculture is mainly carried out in PSREs while development of new crop varieties is the responsibility of private companies. However, despite significant public funding for biotechnology there are few STI programmes on seeds and pesticides. Support for SMEs has been based on the assumption that they would provide the fastest route from scientific knowledge to commercially viable new products and processes and they were expected to generate a substantial number of new, high quality jobs. Most European countries continue to have special subsidy programmes, but most new companies are working in the area of human health biotechnology and not agriculture (Chataway and Tait, 1993).

The agro-biotechnology industry, including seed companies with biotechnology interests, have long lobbied for strengthening IPR for biotechnology in Europe and the European Directive on the Legal Protection of Biotechnology Inventions (Directive 98/44/EEC) was approved in May 1998. The Directive will help to secure biotechnology investment in Europe and to achieve harmonisation of the European market, and thus may contribute to reducing the technology gap between US and European companies (Joly and De Looze, 1996). However, debate continues on the economic efficiency of the patent system to protect and promote biotechnology research and the farming industry and some seed companies are uncertain about the effect of patenting on the free circulation of genetic resources. Also, in some cases, there has been national opposition to implementing the Directive.

Over the last fifteen years, growing attention has been given to the socio-economic aspects of developing biotechnology products. National and EU STI programmes increasingly fund research on factors influencing the commercial success of biotechnology, such as public acceptance, regulatory and approval policies and IPR. However, given the declining share of agriculture in the European economy, the increasing public attention to the environmental impacts of intensive agriculture and the consequent loss of political support, government funding of agricultural research has been steady or declining in most countries, with the exception of Spain. PSREs have been privatised and/or have expanded their contract research for industry and this has raised the question whether they can still be considered as 'public' institutes or whether their research agenda is now targeted to private interests. These changes have meant that seed companies now have to expend more effort on R&D than before, requiring a larger commercial base. Thus, the government retreat from funding agricultural research has contributed to consolidation and specialisation in the seed industry.

4.2.2 Environment, public health and biodiversity policies

Focusing on pesticide and GMO regulation, the precautionary principle (PP) plays a major role in European regulation, particularly for biotechnology. Directive 90/220/EEC on the deliberate release of GMOs to the environment adopted a precautionary case by case approach but because many uncertainties remained about the scope of the PP in such cases, the Commission has also published guidelines for its implementation (CEC, 2000a). However, these proposals still do not meet the expectations of some environmental pressure groups (Greenpeace, 2000) and the EU's reservation of the right to set more stringent standards than other regulatory authorities could be challenged under WTO rules (Vogel, 1995).

Pesticides

Governments use several instruments to influence the use of pesticides by farmers (Vedung, 1998): regulations which influence their targets by means of formal rules and directives; economic instruments which involve financial inducements or disincentives for particular types of behaviour; and information which attempts to influence people through knowledge, reasoned argument and persuasion (Oppenheimer, Wolff & Donnelly, 1996). Regulation and information are the main instruments used in the EU. Among economic instruments, pesticide taxes have been widely discussed but not yet implemented at the EU level. The policies of food processors and retailers which attach strong conditions on pesticide use to farmers' production contracts could also be seen as a very effective economic instrument.

Pesticide registration is now a joint responsibility of the European Commission and national governments. Directive 91/414 requires all active substances introduced after July 1993 to be approved by the EC and added to the 'positive list' before they can be used in the EU. Also, by 2003, all active substances introduced before July 1993 must be re-examined and, if appropriate, included in the positive list before they can continue to be used. Re-examination of the 800 pre-1993 products has been slow, due to difficulties in designing criteria and problems in decision making among Member States.

In response to pressure from environmental organisations and producers of drinking water, governments have recently given more attention to water quality. EU and national standards for water quality are becoming stricter and there is also a clear regional element in policies to protect water supplies. Regulation to protect human and environmental health have also become more stringent, making R&D for new pesticides more expensive. These higher costs reinforce the trend towards consolidation in the agrochemical industry as companies need a larger scale of operation to recoup the costs of registration and testing of new products. However, according to Tait and Williams (1999), risk regulation has largely been beneficial to multinational companies: it has opened up markets for new high value added products when older, off-patent products are banned; compliance with regulations absolves companies from liability that could otherwise result from product defects; and competition may have been eased as the high financial cost and knowledge resource required to comply with regulations has created a barrier to entry.

GMOs

EU policies regulating the introduction of genetically modified organisms (GMOs) aim to protect health and the environment, and to create a unified market for biotechnology (CEC, 2000). Directive 90/220/EEC is complemented by the Regulation on Novel Foods and Novel Food Ingredients (Regulation (EC) 258/97) which sets rules for authorisation and labelling of GMO derived food products and other novel foods.

Since 1997 when public protest against GM crops and foods erupted in Europe, Directive 90/220 has received increasing criticism (Von Schomberg, 1998; Open University, 2000), for example due to the lack of efficiency and transparency in decision-making procedures, the lack of requirements on food labelling and on traceability and monitoring of approved GM crops and their products, and the absence of common guidelines for risk assessment. The limited interpretation of environmental and health effects has also led to dissatisfaction, particularly among NGOs, but also in some Member States, leading to the use of national interpretations of agri-environmental effects and sustainable agriculture.

The laborious EU decision making process on biotechnology issues can be explained by political pressures on parliaments and governments from two conflicting directions. On the one hand there is pressure from environmental and consumer NGOs to restrict the introduction (or in some cases even the development) of GMOs, in combination with low public confidence in industry and government authorities. On the other hand there is strong pressure from industry to support innovation and trade liberalisation by facilitating commercialisation of biotechnology products.

4.2.3 Farm support policies

Historically, the Common Agricultural Policy (CAP) concentrated on securing a fair standard of living for the agricultural community and ensuring security of the food supply at affordable prices and, with this aim, the EU has managed the internal market for many agricultural products, particularly cereals, milk and beef. However, since the early 1990s, the favoured approach has been to lower institutional prices and make compensatory payments, partly in response to international pressure to reduce world market distortion.

Moving away from targeting farmers and food production, the CAP now focuses on integrated rural development, as formalised in Agenda 2000 (European Union, 2000), to secure a multifunctional, sustainable and competitive agriculture throughout Europe. By lowering institutional prices and making compensatory payments, the EU aims to increase the competitiveness of European agriculture and strengthen the EU position in the coming WTO negotiations. The reforms will also ease the process of accession of Central and Eastern European countries and enable Member States to make direct payments to farmers conditional on compliance with environmental provisions.

Short term market and policy fluctuations have little effect on industry innovation strategies as the lead time for new product development is 10–15 years. However, the long term combined strategy for EU agricultural policy, to improve competitiveness and at the same time protect the rural environment by reducing the levels of price support, may have major implications for crop production in Europe and hence for the markets for industry's products. Policy instruments such as cross-compliance and agri-environmental programmes which have an impact on pesticide use also provide governments with direct instruments to control the environmental impact of farming methods.

The relationship between EU prices and the environmental impact of agriculture is not straightforward. While several authors have stressed that high prices lead to more intensive agriculture (e.g. OECD, 1997, p 10), Brouwer and Van Berkum (1996) concluded that lower prices have complex implications, with environmental benefits in one area being offset by environmental costs in others. Also, studies of farmer crop protection behaviour have suggested that, given less predictable market prices for their produce, farmers may become more risk averse in their pesticide use, with greater reliance on routine use of the cheapest and perhaps more environmentally damaging products (Tait and Pitkin, 1995).

Falconer and Oskam (2000) calculated that the 1992 reform of the arable crops regime led to a 3.2% reduction in EU pesticide use, set-aside to a reduction of 2.2%, and price reductions to a decrease of 7.5% (total 9.7%). Given that the arable crops share of total pesticide use is approximately one-third (Brouwer et al, 1994), the total reduction is only about 3.2%.

Kleinhans (2000) has analysed the economic and environmental impacts of the Agenda 2000 proposals produced in 1998, particularly the reduction of intervention prices for cereals which may induce lower intensities in crop farming, decoupled area-based payments, and the abolition of obligatory set-aside which may reduce oilseed production in favour of cereals.

The overall impact of changes in farm support policies on pesticide use seems small but, as shifts in set-aside policies have shown, for individual crops and therefore individual pesticides, the impact can be more pronounced. For the agrochemical industry, changes in production patterns of specific crops may be more important than overall changes.

4.2.4 International trade

In the new WTO round of international trade negotiations, the EU will emphasise the European model of agriculture based on multifunctional farming. International trade is an important issue for the EU given that, as the world's largest importer and second largest exporter of agricultural products, it does not favour a fully liberalised system of farm trade. The EU model also takes account of public concerns for the impact of globalisation on the environment, health, social standards and cultural diversity.

International trade issues relating to GM products have recently become much more important and multilateral agreements may influence the kind of GM products that can be traded. Also, differences in regulatory regimes between the European Union and its trading partners may give rise to trade restrictions and conflicts. Adoption of the precautionary principle could help to restore public confidence (Von Schomberg, 2000) but it could also lead to trade conflicts with the USA and other commodity exporting countries. Issues surrounding the relationship between the Biosafety Protocol and WTO rules have remained ambiguous following the agreement on the Cartagena Protocol in January 2000 (Tait and Bruce, 2000). For example, the preamble states, 'this Protocol shall not be interpreted as implying a change in the rights and obligations of a Party under any existing international agreements' and also 'the above recital is not intended to subordinate this Protocol to other international agreements', the two statements seeming to cancel each other out (Bridges Weekly Trade News Digest Vol 4, No. 5, 8th February 2000).

4.2.5 Developments in the food processing and food retail industry

The food production and distribution chain consists, in addition to companies in the seed, agrochemical and biotechnology industries, of farmers, food processors, wholesalers, retailers and consumers. Developments in processing, distribution and consumption influence decisions by farmers and thus the market prospects for seeds and agrochemicals. If the consumer does not accept GM foods, the farmer will not grow GM crops and the seed company will not develop GM crop varieties. Seed companies that have begun to develop GM varieties in anticipation of public acceptance may experience financial difficulties given the current poor market prospects for transgenic crops in Europe. Similarly, if consumers demand more environmentally friendly products farmers will change their cultivation practices to use fewer or different pesticides, or even shift to organic production systems. Such changes are often accompanied by changes in the crop varieties used, giving a signal to the seed industry to develop varieties with the required characteristics.

European consumers are demanding higher quality products, more convenience products and more variety in food products (Grunert et al., 1996; Gordon, 1998) and are increasingly concerned about food safety and quality, environmental sustainability and ethically appropriate methods of production (Blandford and Fulponi, 1999). As a result governments are implementing more stringent regulations, e.g. on pesticide use, and food processors and retailers are also increasingly paying attention to consumer concerns (Brouwer and Bijman, 2000).

Consumer concerns about GM food products have also had an impact on the choice of farm inputs. Data from the Eurobarometer survey of November 1999 suggest that Europeans are increasingly opposed to GM foods (Gaskell et al, 2000). Between 1996 and 1999, respondents supporting GM foods decreased from 31% to 22% while opponents grew from 39% to 53%. In response food processors and retailers labelled GM food products and formed consortia to develop common practices and criteria regarding inputs, e.g. non-GMO ingredients and lower pesticide use (Tait and Bruce, 2001). This co-operative approach aims to maintain consumer confidence in product quality, to establish Europe-wide supply chains which meet common or minimum standards and to avoid competition for 'non-GM' or low 'pesticide' products (see Annex B 11).

4.3 Potential impacts of policy and regulation on innovation

Public policies here set the boundaries within which private firms seek to exploit market opportunities and technological capabilities and they also interact with social and economic developments in the food industry, food retailing and consumption. We have used the technique of cognitive mapping to summarise the range of policy impacts on industry and PSRE strategies and the interactions among them. Figure 3.1 thus shows how we envisaged the likely interactions on completion of the first Phase of the PITA project under Objective 1 (See Annex B1 for a fuller explanation of these hypotheses). Although these hypotheses framed our research for objectives 2 and 3, the research outcomes have produced richer, even if sometimes contradictory conclusions, as reported in sections 5 to 10.

Reading cognitive maps

The statements, or concepts at the top of the maps represent the range of possible key policy impacts on the industries, with the reasoning/logic represented below them.

Rules for developing and interpreting cognitive maps are as follows:[1]:

(i) Concepts

Maps consist of concepts linked by arrows or lines. A concept is expressed as a short statement covering a single idea or notion, for example assertions about components of a strategy, causes of a problem or means of improving a situation.

Concepts can involve two contrasting 'poles', i.e. they are bi-polar. Where there is a '…' in the middle of a concept, this indicates X 'rather than' Y. If the second pole of this relationship is not specified in a concept it implies 'X rather than not-X' (friendly … not friendly).

(ii) Links

Links describe relationships between concepts. Along with the concepts, they form a line of argument, a description of a problem or the components of a strategy.

They cover a range of different types of relationship, including *causal and connotative*.

Standardise indentation below

Causal links:

A → B indicates that concept A *leads to, or contributes to,* B or A *affects* B.

Connotative links:

A —— B implies that the two concepts are associated in an unspecified way.

Positive and negative links:

Unless specified otherwise, links are assumed to be positive, i.e. the first pole of one concept leads to the first pole of the linked concept. Where a negative sign is attached to a causal link this indicates that the first pole of one concept leads to the second pole of the consequential concept (e.g. A leads to 'not-B).

Further information on cognitive mapping is included in Annex C2.

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[1] Based on the Reference Manual for Decision Explorer Software, pp8-14, Banxia Software Limited, 141 St James Road, Glasgow G4 0LT.

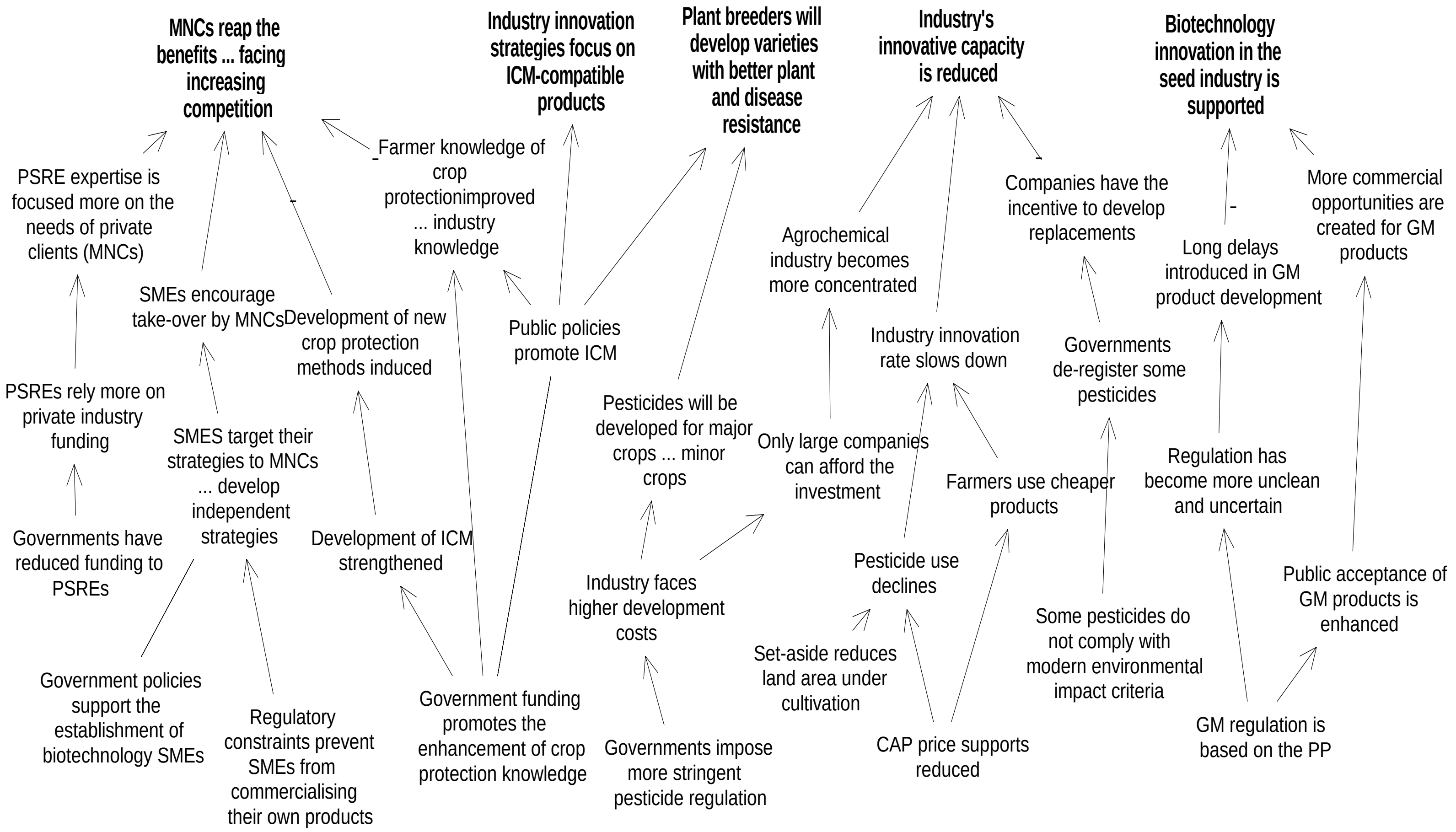

Figure 4.1 Impacts of policy and regulation on innovation

5. Multinational company innovation strategies

Our interviews in the fourteen large companies in the seed, agrochemical and biotechnology industries focused on company innovation strategies and their major determinants, with particular emphasis on the influence of the policy environment as summarised in section 4. This section draws heavily on the approach developed in Annex C1, particularly the concept of technology trajectories and their evolution, and adds to that analysis, bringing in some data from the company monographs (Annexes C3-C16) supplemented by additional academic perspectives.

A focus on technology strategies and trajectories allows us to consider the drivers that influence innovation from the perspectives of the companies and at the same time to gather information that is of concern to this project. Relevant drivers include: the dynamics of the industry sectors including their cost structure; the organisational dynamics of each company, including their technology trajectories; the changing knowledge base, e.g. developments in biotechnology, life sciences and integrated crop protection; and the policy environment. The policy environment and a range of other factors will differ from one part of the world to another, so that companies based in Europe may behave differently from those based in North America. However, successful MNCs will balance their strategies and the timing of trajectories to cope with global variations in the policy environment.

Interactions between multinational agrochemical companies have been dominated by a series of waves of take-overs and mergers since the late 1970s as the sector has become more mature (Braunholtz, 1979; Wood, Mackenzie & Co., 1981; Fernandez, 1985). This process has intensified recently and has been complicated, and partly stimulated, by the introduction of new areas of knowledge from biotechnology (Faulkner and Senker, 1985), bringing agrochemical companies into closer contact with seed companies with their very different cultures, regulatory environments, markets and profit margins.

Issues arising from biotechnology developments are also bringing agrochemical MNCs into much closer interaction than before with food-related industries. Traditionally, the marketing horizon of these companies has stopped at the farm. However, recently there has been an inexorable growth in the number of relevant ‘downstream’ stakeholders that they have to consider, including food and retail enterprises, better organised consumers and members of the public.

Major technological change in any industry sector involves a certain amount of uncertainty. However, the companies involved in this study are having to cope with a shifting base of competition and also changing sets of competitors and customers, and at the same time their policy and regulatory environment is onerous and uncertain. This highly unusual set of circumstances adds greatly to the value of the interview data obtained for this project, from both academic and practical perspectives.

5.1 Industry trajectories and structures

As a result of periodic waves of mergers and takeovers, the agrochemical industry was relatively concentrated at the beginning of the PITA project. Sales of each of the top ten agrochemical companies exceeded $2billion in 1998 (Table 5.1), the total representing more than 75% of the world market. Seven of these ten companies were included in the PITA sample, covering all the major multinationals with their main base in Europe. The mergers that took place during the PITA project reduced these ten companies to seven, including four with a turnover of more than US$ 3 billion (Syngenta, Monsanto, Aventis, and BASF (with Cyanamid)):

- AgrEvo and Rhône Poulenc merged to form Aventis Crop Science.
- BASF acquired American Cyanamid
- the agrochemical divisions of Novartis and Zeneca merged to form Syngenta.

Table 5.1 Sales of the top 10 agrochemical and seed companies

*Agrochemical companies	PITA sample	Turnover ($M)(1998)	**Seed companies	PITA sample	Turnover ($M) (1998)
Novartis	Y	4152	Pioneer	Y	1800
Monsanto	Y	4032	Monsanto	Y	1500
Zeneca	Y	2897	Novartis	Y	900
DuPont	N	2300	Limagrain	Y	700
AgrEvo	Y	2275	Seminis	Y	450
Bayer	Y	2273	Advanta	Y	400
Rhône-Poulenc	Y	2266	Takii	N	400
American Cyanamid	N	2194	Sakata	N	400
Dow AgroSciences	N	2132	KWS	Y	350
BASF	Y	1945	Agribiotech	N	350

*Agrow (1999); **Semences et Progrès (1998)

Companies in the seeds industry are smaller in terms of turnover than those in agrochemicals (Table 5.1). The PITA project involved seven of the top ten seed companies, including three (Monsanto, Novartis and Advanta) that are owned or partially owned by agrochemical companies and one (Pioneer) that was taken over by DuPont during the period of the project.

5.1.1 Technology trajectories

The concept of a technological trajectory has been coined in order to characterise the major changes in patterns of innovation that occur at regular intervals in an industry sector. Perez (1983) related such shifts to broad tendencies in the economy as a whole and elaborated on the concept of successive industrial revolutions, bringing new ranges of products and processes and involving fundamental changes in technological style and a shift in the nature of inputs to production and the relationships among them (Freeman, 1990). In the mid-1980s a new technological trajectory of this nature emerged for the agrochemical and seeds industries based on biotechnology (Tait *et al.,*1990). Section 2.1 of Annex C1 discusses in detail the factors influencing research and innovation in the MNCs studied from the perspective of the technology trajectory concept.

As noted above, in the late 1980s the agrochemical industry was entering a phase of maturity with increasing competition among multinational companies and falling profits as many major products moved out of their period of patent protection. These pressures led to an early round of mergers and take-overs and managers were looking for a new research and development trajectory that would enable them to avoid becoming mere producers of commodity chemicals. To quote a senior industry manager at the time, “We are overdue for another big splash of revolutionary change. … Our creativity needs new outlets. … Biotechnology will drive us into the next golden era.” (Fernandez, 1985).

Given the enthusiasm of scientists combined with the needs of industry, in this new biotechnology-based arena, public and private finance combined to create one of the most sustained and costly examples of ‘technology push’ ever experienced. In pharmaceuticals this has been matched by a strong market pull but in the agro-biotechnology area market demand for products emerging from the new trajectory has been problematic, at least in Europe.

The direction and strength of trajectories are influenced partly by the structure and dynamics of the industry itself and a range of other factors then comes into effect. In the agrochemical industry these include the availability and effectiveness of patent protection, the nature and direction of the regulatory regime and the breadth and depth of the knowledge base. In the seed sector, on the other hand, varieties are protected by breeders rights, regulatory regimes are weaker, and the knowledge base is dominated by plant breeding which is an integrative field at the frontier of genetics, pathology, agronomy and statistics. The new agro-biotechnology trajectory is bringing together these two industry sectors with their different traditions, cultures and knowledge bases, and different modes of interaction with the regulatory environment and the process is creating serious strains in both sectors. In order to understand the current company perspectives on the new trajectory it is important to have some information about the preceding purely agrochemicals and seeds trajectories.

Evolution of the agrochemical industry sector

The agrochemical industry has focused on the production of chemical pesticides to control insect pests, diseases and weeds on crops world wide, with very much smaller scale investment in plant growth regulators, biopesticides and products relevant to integrated pest management (IPM) programmes. Most of the products have been developed with intensive agricultural production and major world crops in mind, but they also have uses in other niche market areas such as smaller scale crops or less intensive farming systems.

As the agrochemicals industry has evolved, the easy crop/pest targets for pesticides have been increasingly covered by effective chemicals and the market, at least in the developed world has become ‘saturated’. At the same time the easier chemicals to discover and manufacture have already been marketed, some for long enough to have outlived their period of patent protection, putting them in the relatively unprofitable ‘commodity’ class. As pesticide markets in the developed world are now relatively saturated, in most cases a new product can only gain a market share by knocking out existing products. If the existing products have already outlived their period of patent protection, and their price has fallen as a result, it will be much more difficult for a new, expensive, patented and hence potentially more profitable pesticide to gain market share.

Added to these competitive pressures, regulatory demands on the industry have inexorably increased development costs for new pesticides. As a result, fewer new pesticides are brought to the market, year on year, and companies concentrate almost entirely on developing products for the major world commodity crops such as maize, cotton, rice, bananas and soya bean which provide markets large enough to recoup the R&D costs. Rhône Poulenc’s estimate of the minimum market size required for profitability of a new pesticide was approximately $50 million (see Annex C14); Zeneca’s estimate of the cost of bringing a new product to market was $100 million (Annex C16).

Faced with such conditions, the companies we interviewed described a range of strategies for retaining and improving their market positions through protecting profitable products in their existing portfolios, ruthlessly shedding unprofitable or marginally profitable products and developing new and more efficient product discovery systems.

(i) Managing the existing product portfolio

Most companies are attempting to rationalise their existing product range, dropping those now giving a poor return, either by taking them off the market or by selling rights to another company, and developing the profit potential of those they choose to retain. Zeneca, for example, has removed approximately 20% of the range of active ingredients from their portfolio in the past five years, avoiding the need for three manufacturing sites world wide.

The decision no longer to sell a particular product is not taken lightly. Off-patent products can be taken up by a competitor and may compete with a patented product already in the company’s portfolio or about to enter it. For example, DuPont decided not to defend its herbicide cyanazine when it was due for regulatory review in the USA because generic manufacturers were unlikely to be able to pay the cost of the review and DuPont themselves had an alternative patented product that could replace it (Annex C16).

Where a company does decide to defend an off-patent product in its portfolio it needs to have good reason to believe it can retain at least partial control of it, either through regulatory hurdles such as standards for purity that smaller companies may not be able to meet or through economies of scale in manufacture. Zeneca's decision to defend paraquat and to build a major production plant in China (Annex C16) and Monsanto's vigorous defence of glyphosate (Annex C11) were both in this category.

Strategic trading of patented products also takes place between companies. For example Novartis' acquisition of the crop protection division of Merck strengthened its profile in acaricide, insecticide and fungicide markets and some of the low-dose active ingredients involved are now well placed to replace products such as organophosphate insecticides which are potentially damaging to human health and the environment.

As noted above there is little growth and probably some contraction to be expected in the pesticide markets of the developed world and companies are looking to the newly industrialising countries in South America and East Asia for major new market outlets.

(ii) R&D strategies for new product discovery

A successful new pesticide molecule has to be able to survive the spraying regime (sunlight, rain, high temperatures); penetrate into a leaf; get to the target site and kill the plant if it's a weed or not kill it if it is a crop; survive metabolism in the plant; be safe to non-target organisms (from insects to cows and to people); not be present in ground water to more than 0.1 ppm; beat the competition; be easy to make and in a safe chemical plant. The attrition rate in the screening process for new pesticides is now approximately 200,000:1, compared to 10,000:1 in 1972 (Green, 1976).

Most multinational companies in our sample have been using new technology to speed up the screening process for new agrochemicals and to improve its efficiency and targeting (particularly Bayer, Zeneca and Novartis) (Steinrucken and Hermann, 2000). The technology involved is largely based on spin-outs from pharmaceuticals development in three main areas:

- using genomics to validate targets for new pesticides, particularly based on natural products;
- using combinatorial chemistry to generate large numbers of new chemicals for screening; and
- using high throughput screening to test very large numbers of chemicals, rapidly, on a range of living targets.

The genomics and combinatorial chemistry are often contracted out to small high-tech SMEs but high throughput screening is done in-house in custom-built facilities. These new methods are not likely to increase the numbers of new pesticides reaching the market each year but they are expected to allow companies to meet increasingly stringent regulatory requirements while still launching one major new product every one or two years. The use of new technology is thus enabling MNCs to develop better quality products, but not a greater number of products.

Evolution of the seeds sector

The seed industry aims to develop new crop varieties with innovative attributes for which farmers will be prepared to pay (see Annex C1). The history of the industry, the techniques used in innovation, the company structure and organisation and the nature of the market combine to make this a very different industry from agrochemicals.

The success of seed companies is based on the quality of their germplasm and this characteristic is often very region specific. This feature of the sector differs to some extent from one crop to another, for example sugar beet is more adaptable to a range of conditions than maize (see Annex C9) but in general new varieties need to be evaluated in the region where they are to be marketed from an early stage of research. Each crop research programme thus requires a network of experimental stations located in the regions where the crop will be grown and centralisation of R&D facilities has not proceeded in the seeds sector to the same extent as in the agrochemicals sector.

Concentration tendencies in the seeds sector have also been weaker than in agrochemicals. Companies are more numerous and smaller (see Table 5.1) and some large seed companies, e.g. Limagrain, still have a co-operative pattern of ownership. Nevertheless, the tendency towards greater interaction between seeds and agrochemicals sectors began in the late 1970s with a small but prominent number of take-overs of seed companies by MNCs. For example, the UK seed company Nickersons was taken over by Shell which then still had an agrochemicals division, with the intention of 'breeding under the pesticide umbrella'. This was a reference to the fact that until then the company had focused its strategies on incorporating pest and disease resistance into high yielding varieties; and this strategy would be changed to a narrower focus on yield-related traits, assuming that pests and diseases would be controlled by chemicals, some of which would be produced by the parent company. This was an early component of the vertical integration process in food production systems which is still continuing.

Seeds have also traditionally been a lower value-added sector than agrochemicals. Innovation through the development of new varieties was less expensive than for pesticides but the rewards to the innovator were more than proportionally less. Thus the seeds sector, although a thriving component of food production systems, has always been less lucrative than agrochemicals.

Hybrid varieties provided one way for plant breeders to generate profits more reliably from their markets, particularly for maize. Farmers were prepared to buy seed anew each season because of the yield benefits they provided and there was no questioning of the breeders' rights to reap a share of the benefits of their innovation in this manner.

Seed breeding has been a cumulative process and companies have succeeded through gradual accumulation of a germplasm base. A company without such a base can only reach a leading position by acquiring a seed company that does have it. Recent exceptions to this rule were sunflower which was a relatively new crop in France in the 1980s, and the entry of Plant Genetic Systems into canola breeding in Canada in the early 1990s.

Some seed companies produce both vegetable and field crops (Cebeco, Limagrain, Novartis, Agrevo, and Monsanto) while others focus only on field crops (Pioneer, KWS, Advanta, Danisco) or only on vegetables (Seminis). Minor crops are usually dropped from the company's range as a part of long-term strategic planning (e.g. Pioneer and Advanta no longer produce vegetable crop seeds). Major field crops include maize (Advanta, Limagrain, Monsanto, Novartis, Pioneer) and sugar beet (KWS, Danisco); cereals are important crops but not usually the most important (see Annex C1).

The large independent seed companies in our sample were all using the techniques of biotechnology (molecular markers and cell technologies) to speed the development of new varieties, to improve the targeting of specific traits and to enhance research capacity (Annex C1). However, where demand, source of knowledge, appropriability and regulation are not changed, the technology trajectory is subject to self-reinforcing dynamics and the dominant design of innovation will not change. The smaller seed companies did not go beyond the use of biotechnology as a new set of tools, complementing conventional knowledge, to improve the efficiency of development of new varieties but not to alter fundamentally the nature of the product.

The use of biotechnology, beyond the above set of R&D techniques, to develop GM crops, generally has to be done in association with a multinational agro-biotechnology company. This strategy increases the costs, opportunities and threats for seed companies.

- The seed company has to bear the cost of introduction of the genetic event in its variety and bear the cost of managing a larger range of products;
- GM crops create opportunities for seed companies by capturing part of the pesticide business and extending the volume of the seed market. For example Seminis (Annex C15) refers to

'intelligent seeds' that reduce the need for agrochemicals and provide healthy and more environmentally friendly food. However, this extension in the seeds market has to be shared with the agro-biotechnology company. Because elite germplasm is the indispensable vehicle for GM crops, the seed company can capture part of the value of this expansion;.

- One threat is that the agro-biotechnology company may give an exclusive licence to a seed sector competitor. Such a threat did not exist when the seed and pesticide businesses were strictly independent. Seed companies have two possible strategies : (i) to group their seed/biotechnology business to act as a 'central buyer' of licences to increase their bargaining power (e.g. the creation of Biogemma in France and the merger of the US businesses of KWS and Limagrain); (ii) to build partnerships with biotechnology companies in order to secure access to the technology (e.g. the links between Advanta and Zeneca, and between Limagrain and Rhône Poulenc).

New agro-biotechnology trajectories

The history and structure of the agrochemical industry as outlined above, heavily regulated and with extremely long product lead times, has forced it to develop sophisticated, long term strategic planning approaches. It was clear from most companies that their continuing success depended on the use of formal foresighting techniques and 'discovery strategies' extending up to 20 years into the future. The shortest term strategic planning horizon in these companies was 5-10 years hence.

For all the multinational agrochemical companies in our sample, strategic planning now involves a combination of chemical and biotechnology developments with varying degrees of synergistic interaction. Multinational agrochemical companies do not envisage a future without biotechnology and in all cases this includes *products* based on biotechnology, not merely using biotechnology to develop better chemicals as outlined above.

There appear to be three distinct approaches to this integrated trajectory (Annex C16):

- Monsanto (from a very early date) and DuPont (much more recently) have invested major amounts of shareholder funds in acquisitions – a strategy described by other companies as 'buying the channel to market', as well as investing heavily in building up their technology base;
- other companies (AgrEvo, Zeneca, Novartis, Rhône Poulenc, Dow) are trying to capture value in a different way – they have invested a great deal of money in the technology and have made some acquisitions to give them a reasonable 'route to market' base, but not as far downstream as Monsanto and DuPont;
- BASF and Bayer are late starters with different strategies for patents, technology and route to market, looking for benefits from their agrochemical businesses to help them to buy into biotechnology, by-passing the earlier innovation phase that other companies have gone through.

(i) Phases of GM product development

The development of the first generation of GM crops, concentrating on input traits such as herbicide, insect pest and disease resistance, has been based on relatively simple technology which had been the subject of scientific investigation for a considerable time and could be implemented fairly rapidly. However, companies have not yet made much money from this technology and they see the next generation of GM crop technology as being much more difficult to achieve.

Characteristic strands of innovation for second generation GM crop products now under development include:

- quality traits such as flavour enhancement;
- better processing and feed quality, animal feed crops tailored to the nutritional requirements of different species;

- agronomic traits;
- improved nutrition in crops such as vegetables and rice (e.g. rice with additional vitamin A and iron, a Brussels sprout with high vitamin C content or traits that would lessen the incidence of heart disease), often described as ‘functional foods’ or ‘nutraceuticals’;

A potential third generation of GM innovations, predicted within 10-15 years and involving a different type of chemical/biotechnology synergy, will see plants being used as factories to develop a wide range of chemicals, including pharmaceuticals and bulk chemicals.

Industry managers generally agree that the input traits present in first generation GM crops have been attractive to farmers but have provided few benefits for consumers (with the exception of Zeneca’s tomato paste (Annex C16)). This is widely accepted by industry as one cause of the widespread rejection of GM crops by European consumers. The output traits now being developed in second generation products are expected to be much more attractive to consumers and hence to remove the stigma attached to GM crops. Zeneca managers observed that input and output-related crop characteristics are different businesses, with 'input' having the farmer or grower as the customer while 'output' goes right along the market chain.

Underlying this rationale is a second layer of strategic thinking by multinational companies in their efforts to extract value from GM crops. Output traits will change commodity crops into specialities which can then be segmented in the market, providing an engine of value. Companies will thus get their reward in two ways: from selling the trait itself and from selling pesticides or other plant protection products to protect a more expensive crop; and managers predict that farmers will want to see this all in one package, i.e. delivered by one company.

The idea that some of the new GM-based output traits in crops would enhance the value of the crop, thus increasing the demand, either for crop protection chemicals or for protective GM-based input traits, is another example of a synergistic interaction between biotechnology and chemicals at the market stage but achieving the value-added requires strategic planning for the whole value chain from the early discovery stages.

(ii) Synergies between agrochemical and pharmaceutical product development strategies

Agro-biotechnology industry managers confirmed that the concept of life science synergies has played an important part in their strategic planning and in the provision of a rationale for major change as the new technology trajectory has evolved. Early interpretations of the term ‘life science’ assumed that, by using biotechnology to gain a better understanding of the functioning of cells across a wide spectrum of species, there would be useful cross-fertilisation of ideas between the development of new drugs and of new crop protection products for agriculture.

The vision in these cases was one of synergy at ‘discovery’ level, where a better understanding of genomics and cell processes, made possible by fundamental knowledge gained in the life sciences can lead to new drugs, new pesticides, GM crops and genetic treatments for disease. At this stage, the research itself often does not have any particular application in view and a close association between the agrochemical/seeds and pharmaceutical divisions can allow the company to extract more value from the original research than would otherwise be the case. Also at the discovery level, given the increasing tendency to contract out the synthesis of new chemicals to companies specialising in combinatorial chemistry or to buy in the services of bioinformatics SMEs, the same contracts can be of value to both divisions of a MNC.

These assumptions were accepted until recently without much questioning, partly to justify the continued retention within the same multinational company of two sectors with markedly different profit potentials, pharmaceuticals and agrochemicals. However, the original conception of a life science sector is now being reinterpreted.

The synergy worked well where both partners are interested in sources of *chemical* novelty, but not in the *gene* area. Functional genomics, as a platform technology, can help both sides to invent novel and profitable chemicals but unlike pharmaceuticals, in the agro-biotechnology sector there are also major commercial opportunities in the creation of GM crops. The large scale marketing of genetically modified organisms is not a significant factor in the strategies of pharmaceutical companies. Although experience in the USA and other countries has indicated that GM crop development is potentially very profitable, the negative public reaction in Europe has created potential conflicts of interest between the two industry sectors.

Over a 20 year timescale useful synergies between pharmaceutical and agricultural areas of biotechnology may again emerge, for example medicinal benefits and other health-related output traits from crop plants. However, by the time such synergies do emerge managers expected that there would no longer be a link between the agrochemical and pharmaceutical divisions of companies (Annex C16).

Thus, beyond the fundamental discovery stage, there is currently little synergy between the down stream product development processes of the agrochemical and pharmaceutical sectors. When it comes to near-market development, managers interviewed for this project commented that their natural partners were in the food processing and retailing sectors rather than in pharmaceuticals.

(iii) Synergies between chemistry and biology in agro-biotechnology.

Companies were aware at an early stage that the new trajectory would be based on synergies between chemistry and biology. However, for a variety of reasons, intimate collaboration between biotechnology and agrochemicals is only just beginning to materialise after about 15 years. One important factor has been the need to change organisational cultures among staff who were largely trained as chemists, not biologists. As agrochemical companies began to link up with the seeds sector, managers also had some misconceptions about the nature of the seeds business and the future of agrochemicals and biotechnology as joint initiatives.

- Seeds, unlike chemicals, were traditionally a low value added component of the sector and companies had to learn how to extract enough value from the product to pay for the more costly research and development where biotechnology is involved, and also to cover the costs of a more demanding regulatory system.
- Companies also realised that some of the interactions between agrochemicals and biotechnology could be antagonistic rather than synergistic, especially for the input traits developed in the first generation of GM crops. Incorporation of disease and pest resistance genes into the crop would diminish the market for insecticides and fungicides. Herbicide resistance, on the other hand, reinforces the market potential of some herbicides and no GM developments are currently envisaged that could substitute for herbicides.

Monsanto's strongly vision driven approach and its very early adoption of a combined agrochemicals and biotechnology strategy forced the industry as a whole to travel faster along the new trajectory than it might otherwise have done. The strategy has been implemented through multidisciplinary teams based around crops, regions and products, and including members from different functions, marketing, regulation, agrochemicals and biotechnology.

Monsanto began to sell seeds on the basis of crop protection rather than increased yield, as had previously been the case. The company was able to do this largely because of its reliance on a single product, the very successful herbicide glyphosate, for most of its agrochemical profits. Thus, for Monsanto, a combined agrochemical and biotechnology strategy created only synergies and no antagonisms and the approach began to yield startling commercial rewards in the late 1990s with a rapid expansion in the area of GM corn, soybean and cotton planted in North and South America.

Other companies were caught out by the speed with which Monsanto was able to implement its combined strategy and are only now developing serious strategies to integrate their agrochemical and biotechnology divisions, creating synergy between chemicals and biotechnology at the commercial level. They have realised that if they fail to take up this challenge they may risk losing their global supremacy, depending on the commercial outcome of this trajectory given current uncertainties in Europe.

For example, in June 1999, Novartis initiated a new agribusiness strategy (called Project Focus), with the objectives of growth, fitness and sustainable leadership. Global teams will operate jointly between crop protection and seeds divisions and will define overall strategies on a crop by crop basis to deliver a management system which takes care of the yield characteristics and composition of the crop and its capability to resist environmental, biological and climatic stresses. The overall package of items for the farmer will involve both chemistry and genetics (including traditional breeding and gene technology).

Project Focus will go beyond the recent biotechnology R&D focus on input traits and will increasingly focus on the next generation of GM targets, crop output traits, chemical trait regulation, marker assisted breeding and genetics/genomics. The challenge for a company like Novartis with very strong agrochemicals and seeds divisions will be to keep the core businesses running while managing the new trajectory. Novartis sees this as an issue of flexibility, a subtle rather than a dramatic shift, 'keeping a balance along the vector from current business to the new nutraceutical environment.'.

Zeneca's strategy considers interactions between crops, pesticides and GM technology and likely impacts on future markets, optimising the combination of chemicals, genes and information. An early example can be seen in the company's fungus resistance/fungicide combination. The synergistic interaction evolved in this case more by accident than by design – the two components were being developed on separate tracks and were brought together at the near-market stage. However, this can be seen as a normal part of the learning process that all companies have to go through when re-orienting their strategies to a new technology trajectory. Following from this experience, similar strategies are now in place elsewhere in the company's portfolio, and Zeneca is aiming for 'crop leadership on a limited number of strategic crops, having a superlative offer involving chemicals and biotechnology on these crops'.

Thus, the nature of the technology, coupled with competitive interactions among companies, are leading to a redefinition of strategic targets throughout the industry, with a focus on the crop as a whole and the provision of an integrated package of seed and chemicals. As a corollary of this strategy, companies will, in the short term, concentrate on global commodity crops. However, as noted below, a parallel but slightly longer term strategy for the second generation of GM crops is the creation of higher value niche markets based on crop output traits.

(iv) New patterns of alliance in the agro-biotechnology industry

The agro-biotechnology trajectory involves both changes in the nature of chemical innovation and in the development of GM crops and this leads to fundamental differences in the technology trajectory for agro-biotechnology companies, compared to that experienced by pharmaceutical companies. In addition to the uncertainties created by the market and policy environments, the trajectory itself is much more complex and requires the creation of radically new systems within companies and in relations among companies. This in itself would justify the reorientation of the agro-biotechnology sector, away from its close association with the pharmaceutical sector, in addition to the market and consumer acceptance problems that are usually cited as reasons.

The demise of the pharmaceutical/agrochemical synergy in the evolution of the life science trajectory has focused more attention on the underlying synergy between chemicals and biotechnology and on the need for new and different patterns of alliance among large and small companies.

In discussing the relationship between agro-biotechnology and pharmaceutical divisions several companies noted that, beyond the early discovery stage, there were few useful synergies between the two. More natural partners in developing routes to capture value from the new technology were seen to be multinational food processing and distribution companies. For example, Novartis noted that within its group of companies, the vegetable group works closely with the consumer division, but they could equally well work closely with any consumer or functional food organisation. There is just as much opportunity to work with a company outside Novartis as there is within Novartis, including other pharmaceutical companies or other functional food companies.

The changed pattern of development within the industry involving a strengthening of the linkages between agro-biotechnology divisions of different companies and weakening of links between agro-biotechnology divisions and their pharmaceutical counterparts, was thus generally seen as a positive development, offering opportunities to cultivate more useful channels to market the new products.

With the shift of power from production to consumption, the agrifood chain is thus experiencing a gradual shift from mass production to dedicated production. Mass production is not over but there is a growing market for food that is produced according to specific quality requirements. Such changes may constitute major opportunities for agri-business firms, some of which have developed "from seed to store" innovation strategies:

> "What you're seeing is not just a consolidation of seed companies, it's really a consolidation of the entire food chain. Companies … (that) want to continue to be in the food and feed production business, are all trying to secure a spot along that chain." *Rob Fraley*, Farm Journal, Oct. 1996[2]

The new focus of agro-biotechnology MNCs on the crop as the basis of their strategic planning creates major challenges for purely seed-based companies. SMEs can probably continue to exist on a niche market basis but the larger seed companies are unlikely to find large enough slots in the market to compete with MNCs and their new combined strategies. Depending on the outcomes for GM crops in Europe, it may be unrealistic to expect such companies to survive as large independent companies in the new agro-biotechnology trajectory.

5.1.2 Cross sector and cross company comparisons

The new agro-biotechnology trajectory discussed above is still in its early stages of development and there is competition among companies to find the most successful combined strategies for success in this area. The diversity in the strategic frames of the 14 companies studied is summarised in Table 5.2.

Monsanto stands out as being *technology driven, pushed forward by a conviction in the vision of being a knowledge based company developing leading edge technology*. The company aimed to be first in the field and to develop a commanding position by marketing its products aggressively to farmers. Before the first product was ready to market, Monsanto had *"made an upfront investment in facilities and the best scientists"* and had made *"a commitment to a 20 year development of GM crops"*.

Zeneca also developed a new knowledge base in the 1980s, with a very different marketing strategy, listening carefully to public concerns and looking for customer value in collaboration with food processors and retailers. Its tomato puree was labelled as containing GMOs[3] and was cheaper than non-GM products.

Limagrain's project and innovation strategy is shaped by its identity both as an international seed producer and as a farmers' co-operative. The vision of *'an agriculture of the future for the benefit of mankind'* reflects its focus on agriculture (not life sciences), an agriculture of the

[2] Quoted in Vorley and Kenney (1998).

[3] Cf. Tait and Chataway (2000) for a detailed comparison of Monsanto and Zeneca.

future (not a 'farmers agriculture') taking advantage of technological progress. The reference to 'the benefit of mankind' is embodies a humanistic world view which sees profit as being at the service of human development, a view which is possible since the shareholders (farmers) expect the co-operative to deliver such benefits, rather than dividends.

Table 5.2 Company vision statements and strategic frames

Strong agrochemicals and biotechnology integration	
AgrEvo (Annex C4)	• from plant protection to plant production: offer farmers products for enhancing the productivity of plant protection through innovation in chemistry, biotechnology and breeding • food for all people
Monsanto (Annex C11)	• be at the forefront of new technology; dominate the life science industry sector; • find large blockbuster products • oppose the PP and GM crop segregation
Novartis (Annex C12)	• customer oriented and technology driven, integrating breakthrough technologies and synergies between crop protection and seeds • agribusiness strategy based on whole food chain and improving links with stakeholders • support for a strong version of ICM
Zeneca (Annex C16)	• from crop protection to crop enhancement • improve competitive position through investment, acquisition and partnership for research and enabling technologies • gain access to 80% of world market for agribiotech–primarily output trait, speciality and integrated crop management opportunities
Traditionally agrochemicals, now incorporating biotechnology	
BASF (Annex C5)	• be one of the world's leading chemical companies • increase globalisation via Verbund (integrated production and distribution systems) • catch up in agribiotech (be 'fast follower' and become one of the major players in plant biotech; focus on life science synergy)
Bayer (Annex C6)	• become world's leading integrated chemical and pharmaceutical company • be responsible; support policies allowing consumers freedom of choice through labelling GM products
RPA (Annex C14)	• maintain strong positions in pesticide market • fill gaps in maize, soya and cereals • make company more flexible
Seeds and biotechnology	
Advanta (Annex C3)	• maintain position as one of the largest seed companies in the world, with global sales reach • provide added value for farmers, down stream technologies and consumers through superior genetics and essential technologies
Cebeco (Annex C7)	• creation of value for farmer-members • work in a customer-oriented and knowledge driven way, expanding within Europe
Danisco (Annex C8)	• be a world class supplier of the global food industry within all core business areas, divesting non-core components • be large and diversified, growing organically • product innovation to keep up with competitors; be close to consumers, with new products adding to old competences not substituting for them
KWS (Annex C9)	• customer (=farmer) orientation • strong product development, maintaining market leadership in sugar beet

Limagrain (Annex C10)	• provide an agriculture of the future for the benefit of mankind • enhance the value of agriculture production in order to enable farmers to remain profitable in face of agricultural policies
Pioneer (Annex C13)	• consolidate global leadership in soya as well as maize, focus on quality as well as agronomic traits, and increasing weight of non-research functions in a research-led company • increase global reach with aggressive research strategy and by investing in products with European importance
Seminis (Annex C15)	• strengthen and maintain leadership position in global hybrid seeds for vegetable and fruits • capture value through whole food chain

With the exception of Monsanto, Pioneer and Seminis, all the companies interviewed could be described as ‘European’ even although they operate on a multinational level. The sources of this European-ness probably lie in the home base of the company and the pervasive influence this has on the organisational culture.

The geographical scope of a company explains some differences in the way it perceives and interprets public policy signals which are specifically European. Annex C1 presents data on sales distribution and R&D investment and it is noticeable that European agro-biotechnology MNCs are usually strong in Europe and the US and hold a similar share of the Latin American market to US companies. US firms are much stronger in North America and less strong in Europe.

Localisation of R&D capacity also varies across companies. Where R&D facilities are concentrated in a small number of locations as for agro-biotechnology MNCs, the biotechnology R&D of companies has often been located in the US to benefit from American science and its ‘can-do’ mentality (Senker et *al*., 1998) (Annex C12). When R&D is more widely distributed, as for seed companies, the degree of concentration of *decision making* is important, for example Pioneer has more than 100 research stations world-wide but decision making and data processing is centralised in the US.

European companies are thus more dependent on the European context and are also more sensitive to European political and regulatory cultures, including the PP and the more active stakeholder approach demanded by European citizens.

US companies take a US-based reference point for agricultural policies. The lack of understanding of, and lack of attention to, the formation of European public policies may explain the gap which has appeared since 1999 between US-based and European companies in this sector. For example, many European companies openly blame Monsanto for the public opinion backlash against GM crops in Europe. Monsanto now aims to understand European cultures better in order to "decrease hostility towards the company" and to obtain a "workable risk regulation policy".

6. Policy influences on company decision making

The previous section set the scene for consideration of policy influences on company decision making. An understanding of the history of the industry sector, the way it is evolving and the context within which policies and regulations operate is essential before one can begin to draw inferences about their impact on product development strategies and the environmental performance of the products that emerge.

Monitoring of different policy sectors tends to be distributed across different functions in the company. For example, developments in WTO negotiations and CAP reform will probably be monitored by commercial people; risk regulation of pesticides and GM crops by Regulatory Affairs; and public and consumer attitudes by Public Affairs. These issues are brought into the R&D picture at an earlier stage than used to be the case through the multidisciplinary, crop-based teams now being set up by most companies, but they are generally not yet well integrated into decision making. Nevertheless, the influences of interest to the PITA project are embedded in the company discourse as a whole, and emerge from the analysis, as indicated in the Company Monographs, Overview and Cognitive Maps included in Annex C. As indicated in the analysis in Annex C1, there is a strong link between the world views of companies, their cognitive filters and the organisational and strategic frames they build.

6.1 Foresighting and European innovation policies

Section 5 referred to the sophistication of the foresighting techniques adopted by multinational companies, scanning a 20-year planning horizon as part of the discovery strategies which are the starting point for the development of new high-tech products, chemical or genetically modified. However, forecasting is carried out almost entirely on the basis of:

- technology – what is likely to be technically feasible in future; and
- business and markets – where will the major crops be grown in future, how profitable will they be, what crop protection problems will they suffer from.

Despite the sophistication of technology and business forecasting, companies readily admit that both areas have a habit of generating surprises – events move faster or slower than predicted, new technology or business options emerge unexpectedly or options that once seemed promising are closed off.

Companies also monitor their policy and regulatory environment and take account of likely short term shifts (e.g. the imposition of a pesticide tax) and general long term trends (regulatory review of chemicals) (see Annexes B1 and B3) in development decision making for new products. Policy and regulatory changes can close off some business or technology options and can open up new ones. Forecasting in this area, along with a much earlier consideration of public relations issues than used to be the case, is only now becoming an important component of company strategies. This change has been driven, not by public policy or regulatory initiatives, but by negative consumer attitudes backed up by organised boycotting of the products of intensive agriculture, a development which could be seen as a new *ad hoc* instrument of global governance (Tait and Bruce, 2000).

Senior managers in Novartis (Annex C12) noted that if they want to create opportunities in Europe they “ … have to position themselves in the context of the long term strategies of European society”. They see the new societal mandate as being to achieve an emission-less agriculture that is also a source of leisure for the majority of the population and is a keeper of biodiversity. When they anticipate changes, they see themselves as having two options, either to shape whatever comes along or if they cannot influence it then to adapt internally. However, this recent change in perspective is not universally understood either in the company or in the industry as a whole – a paradigm shift is needed where people have never before had any doubts about the societal value of their products.

The agrochemical industry has in the past become adept at managing technological and market uncertainties. As we note below, the policy and regulatory environment for the production of pesticides has in the past acted to moderate this uncertainty and to make it easier for companies to cope with long product lead times and competitive pressures. However, when turbulence occurs simultaneously in the regulatory and policy environment and in an industry's major markets along with a shifting technology trajectory the level of uncertainty may exceed what any company, no matter how far-sighted, can cope with.

European policies in support of innovation are directly relevant to companies' R&D programmes which rely on the availability of a good supply of well trained scientists–this is a major factor in decision making on where to locate R&D facilities. Europe is not yet seen as being problematic in this sense but there is a feeling of being fairly close to a threshold.

As regards the generation of new ideas, the US is seen as the best location for the 'can-do' mentality that wants to make things happen whereas the European scientific culture is seen as more effective for the careful, meticulous research that is needed further down the product development stream.

Novartis (Annex C12) pointed to a need for change in EC decision making processes on innovation for agriculture. They noted that European institutions tend not to see a role for innovation in their long term agri-food strategies, unlike most other agriculturally productive regions of the world. They pointed out that EC policy makers do not have a place in their philosophy for what industry is doing and concluded that industry has to take several steps back and engage in open-ended debate with policy makers about the technological future of European agriculture. Until this takes place, the public acceptance problem will not be resolved and industry cannot implement its very long range R&D strategies.

6.2 Policies impacting on markets

6.2.1 WTO negotiations and CAP reform

CAP reforms were seen as being overall framing policy instruments which are relatively predictable (Annex C1), impacting on industry by affecting the market for its products. Seed companies which were significantly oriented towards European markets (Limagrain, Cebeco and Advanta) were most sensitive to this type of policy instrument, particularly shifts in subsidy away from some crops. Such changes alter the location of production of the affected crop and hence the relative commercial advantage of particular varieties. They also lead to crop substitution and can alter the balance of advantage among competing seed companies in a region (either within the EU or globally).

The following perspectives on CAP reform were given in the company monographs (see Annex C1):

- Limagrain expected maize production (for fodder and for grain) to move from Western to Eastern Europe while Cebeco and KWS were predicting fodder maize production to increase;
- European cereal production is expected to increase and Limagrain, Monsanto and DuPont have all invested heavily in this area;
- oilseed production is expected to decline and companies are reducing or abandoning development programmes for oilseeds;
- sugar beet production is expected to decline slightly;
- Zeneca referred to set-aside as a 'new crop' for which they were able to provide herbicide inputs;
- given the lack of long term commitment in the EU to crops such as peas or soya bean, seed companies are generally not investing in protein crops.

CAP reform will thus affect the crops which are grown, and the intensity of production systems and hence will have an impact on the European environment. However, as indicated in Annex B1, predictions about the actual impact of CAP reform on the intensity of production are not unanimous – some research findings suggest that it will lead to more intensive production and others suggest the reverse.

WTO negotiations are likely to reinforce the impact of CAP reform, operating on a global scale, shifting the location of production from one region to another as the reduction or removal of subsidies for crop production affects their relative advantage.

However, WTO impacts have not so far been as predictable as some companies expected. Monsanto, for example, confidently expected to be able to gain access to European markets for its GM maize and soya by invoking WTO rules on trade liberalisation. However it has not yet been able to do this. Some MNCs were concerned that US pressure on the WTO on this issue would exacerbate European public concerns about GM crops and further delay their acceptance.

6.2.2 Public policies to moderate pesticide use

Demonstrable risks arising from pesticides are dealt with by the regulatory system but at national levels in the EU, a range of additional policy initiatives are designed to affect the market for pesticides by influencing their use at farm level.

CAP and WTO reforms are putting inexorable pressure on production-related subsidies but allow subsidies that are intended to provide environmental benefit and to contribute to the multifunctionality of European agriculture.

Subsidies to encourage farmers to convert to organic or integrated crop management (ICM) systems form part of these packages and could create markets for organic seeds, seeds with a stronger focus on pest and disease resistance or pesticides that are useful in integrated pest management (IPM) systems. Companies participate in a range of ICM initiatives, including LEAF in the UK, FARRE in France and Agrofuturo in Spain with varying degrees of commitment to the pesticide minimisation components of these systems. The definitions of ICM from AgrEvo (Annex C4) and Novartis (Annex C12) refer to being cost-effective, environmentally sound and socially acceptable, echoing Zeneca's commitment (see below) to the 'triple bottom line' of accounting for sustainable development.

These developments are so far having only a marginal impact on company strategies – while the markets they are creating are growing rapidly, it is from a very low baseline and companies are waiting to see how they will develop in the longer term before investing heavily in them.

Some European countries have instigated pesticide reduction programmes or have imposed taxes (selective or unselective) on pesticides in an attempt to reduce national levels of usage. As with other forms of pesticide regulation, this was generally an accepted part of the pesticide regulatory background for companies and they factored it into their decision making. However, several managers and the European Crop Protection Association did comment on the inefficiency of pesticide taxes in achieving their aim and expressed a preference for incentives rather than dis-incentives as policy instruments.

6.3 Risk regulation

Companies are anticipating continuing pressure on pesticide use in agriculture, particularly on some older products which are believed to cause environmental or human health problems and on the other hand are hoping for a resolution of the current uncertainty surrounding the acceptability and risk regulation of GM crops in Europe. However, Europe is not necessarily the dominant influence on product decision making for an MNC. The US system of pesticide registration is much more important on a global level that that of the EU, and even in the case of GM crops, companies such as Zeneca which were not planning to launch products in Europe in the near future had not yet had their marketing plans affected by the EU problems.

6.3.1 Pesticides

In both Europe and the United States, central registration systems exist in theory for pesticides, but they do not operate fully in practice in either administration. In the US, individual states often assume the right to take unilateral action and in the EU the principle of subsidiarity is frequently invoked by nations to regulate on the basis of local issues.

For most companies, pesticide regulation impacts on R&D strategies in a routine sense. Zeneca saw the European regulatory system as very important for pesticides destined for wheat crops, but the US system was the dominant one for all other crops.

Particularly important from the point of view of this project, both Zeneca and Novartis considered that where a product had some environmental advantages, the policy and regulatory environment was improving in both the EU and the US. Pesticide regulation was seen as having the potential to create markets for new pesticides. Attempts in the early 1990s to use regulation in this way were seen as ineffective because they did not create any incentives – regulators were trying to get greener products with no levers or rewards for industry and there is no evidence so far that a more modern chemical will replace older ones in the market. Novartis also commented that R&D based companies should, when they have new and better technology, replace old products. However, where the older products are cheap there will be pressure from farmers to keep them on the market, and a regulatory incentive would probably be needed to encourage change and to enable the company to promote it effectively.

Two regulatory instruments, one European the other American, were mentioned specifically by several managers in the context of ‘cleaner’ technology:

> The EC Drinking Water Directive (80/778) was the stimulus for one of the most important filters in the early screening of pesticides. Any product which had a tendency to be mobile in soils, no matter what its other attributes, would be rejected at that point. This is regarded pragmatically by industry as part of the innovation process in that, among other things, it creates openings to replace old products that cannot meet the new standards. However, there is also some evidence that it is leading to the rejection of some chemicals with a potentially cleaner environmental profile than the current range of products but with a high mobility in soils. As noted above, the proportion of new chemicals tested that can meet today’s very rigorous environmental standards is very small indeed. Unnecessary loss of potentially useful new products may be a greater loss to the public than to industry. The public costs of operating the Water Quality Directive on the basis of this single criterion may be greater than the public benefits.
>
> The second regulatory instrument is the US Food Quality Protection Act (FQPA), 1996 (www.epa.gov/oppfead1/fqpa). This has introduced a new safety standard, reasonable certainty of no harm, that must be applied to all pesticides used on foods, plus a system to expedite the approval of safer pesticides. This ‘fast track’ regulatory process for products which can claim environmental or health benefits compared to the existing product range has changed the basis of competition among companies, moving from individual safety assessment to comparative risk analysis, leading to greener products rather than products directed to a specific market. These factors have a knock-on effect on the rest of the world given the US influence on import tolerance levels. A compound which has ‘safer’ status will knock out or limit the impact of products already on the market.

Both instruments have been criticised by industry managers for being based on precaution rather than ‘sound science’. However anecdotal evidence suggests that the FQPA is more unpopular among junior than among senior managers; and more unpopular among US than among European companies. Industry opinion of the Drinking Water Directive was more uniformly critical. According to some managers it is preventing potentially useful new products from reaching the market place while the FQPA is creating the kind of regulatory incentive for 'cleaner' technology that some mangers saw as desirable. The difference may lie in the fact that one discriminates among pesticides on the basis of presumed, but not proven, environmental and health benefits, while the other fails to discriminate among pesticides on the basis of presumed, but not proven, environmental and health risks. These comments are not intended to imply that either piece of legislation should be changed; they are used here as examples of different approaches to risk regulation and a demonstration of different types of impact on industry decision making. We should learn from such examples in designing future policies and regulations.

6.3.2 GM crops

Almost unanimously the greatest regulatory concern among company managers was the uncertainty surrounding the eventual system for risk regulation of GM crops in Europe and even the date when the current impasse might be resolved. The agro-biotechnology industry has become adept at coping with complex and demanding risk regulatory systems but, as noted above uncertainty about the regulatory system is severely inhibiting of product development *in the long run*. However, the very length of the product development cycle does give companies some protection against short-term uncertainty. Strategic decisions are being made today for products that will not reach the market for at least another five years and many managers were hoping that the current regulatory problems in Europe would be resolved in that timescale and/or that the negative public image of the industry would improve. In the meantime, being multinationals, they were concentrating their efforts on markets outside Europe.

The European problem was seen as political rather than regulatory and the solution was seen to lie mainly in recovering a favourable public opinion for the industry and its products. To achieve this, companies were advocating more effective dialogue with a wider range of stakeholders than had been the case in the past (see below) and also a stronger focus on second generation GM crop products such as functional foods and nutraceuticals that were expected to have a greater publicly perceived benefit than the first generation of GM crops. The important issues for industry to address were seen by Novartis as:

- comparative safety versus absolute safety and
- perception of risk versus risk monitoring and mitigation.

There was a recognition in Novartis that there may be some risks that cannot be identified during experimentation and therefore acceptance of the need for lifetime monitoring of products, perhaps by seed companies or agricultural extension agents, building on the current systems for monitoring the spread of new diseases among crops.

6.4 Shareholders/stakeholders and other key actors

Although there was general recognition among companies of the need for greater openness in dealings with stakeholders there were important differences among companies in the way client/customer/stakeholder issues are managed. The trend is towards a more open, multi-stakeholder approach to strategy but many companies feel uncomfortable with this, and stay more narrowly focused on the 'farmer' as customer and their shareholders as controller. Such differences may be partly related to differences in ownership structures, for example among companies which depend on volatile stock-market ratings (Monsanto and Zeneca) and those which have a more stable set of shareholders including industrial capital and banks (AgrEvo, BASF, Bayer, Novartis, RPA). Some companies are family owned (KWS) or farmer co-operatively controlled (Cebeco, Limagrain).

Some companies see themselves as firmly embedded in a system where farmers are the primary client (e.g. Monsanto). However, others accept that food processors and retailers are increasingly important actors (Novartis and AgrEvo) and many confirmed that consumers and public opinion were much more important than they had been in the past

The issue of stakeholder values (as opposed to shareholder values) has emerged recently as an important dimension of company management. Stakeholder values may impact on companies through market mechanisms (ethical consumption, boycotts), the political system or shareholder meetings (ethical funds). They are generally weak but accumulate as a result of frustration and dissatisfaction. A time lag between the communication of stakeholders' values and a response in terms of a firm's behaviour may undermine company legitimacy and weaken its long term sustainability.

For seed and agro-biotechnology companies, the management of value in the agrifood chain is increasingly dependent on the perception of end consumers rather than on selling products to farmers (Koechlin and Wittke, 1998) and this gives greater bargaining power to food processors and retailers. There is thus a need to take better account of their interests and values.

6.5 Industry views on sustainable development

Almost all companies in our sample have for some time used the concept of sustainability to describe their vision of the interactions between agriculture and the environment, involving both feeding a growing world population and at the same time protecting biodiversity. A recent element in this argument is the role of GM crops in reducing dependence on pesticides while further increasing crop yields (Conway, 1997). To paraphrase some of the company approaches to sustainability:

> BASF (Annex C5) describes sustainable development as a long term on-going responsibility which they can adapt to meet regional needs. They refer to the need for commercial success before they can develop new technologies based on sustainability principles.
>
> Monsanto (Annex C11) sees the risk of *not* pursuing high yielding agriculture, including GM crops, as high – 'using information is one of the ways to increase productivity without abusing nature'.
>
> Advanta (Annex C3) continues to focus on conventional agriculture, contributing to sustainable development through developing better varieties with higher yield and enhanced pest and disease resistance.
>
> Novartis (Annex C12) observed that sustainable agriculture does not mean organic agriculture but includes the use of crop protection products in such a way that our great grandchildren will be able to produce the food they need.
>
> KWS (Annex C9) referred to the development of agricultural crops as a renewable source of raw materials for industry.
>
> AgrEvo (Annex C4 believes that agricultural production and biodiversity preservation can only proceed in harmony if the production is high yielding.
>
> Danisco (Annex C8) referred to sustainability in terms of stakeholder demands (human rights, employee conditions, social responsibility) and the ethical/social context.
>
> The Cebeco Group (Annex C7) has only recently designated sustainability as one cornerstone of its policy, along with value creation, chain development and internationalisation.
>
> Zeneca (Annex C16) talked in terms of the 'triple bottom line', emphasising the need for financial, social and environmental sustainability but stressing that without financial sustainability the other two were irrelevant as far as the company was concerned.

Where environmental sustainability was included in a company's conception of sustainable development it often involved linking GM crop and pesticide strategies (see below).

6.6 Policy interactions with the MNC life science trajectory

The evolution of the life science trajectory in the agro-biotechnology industry is heavily influenced by the policy context and other issues that are the subject of the PITA project. For the policy maker, it is important to understand in depth the constraints and other influences on industry motivation and how policy can be tailored to have the optimum influence on the environmental impact of agriculture without undermining the profitability of two major industry sectors in the European economy.

Figure 4.1 summarised our understanding of the potential impacts of policy on industry decision making prior to conducting the survey of managers. Subsequent sections have summarised the industry perspective on these issues based on the information from our interviews. Faced with market, policy and regulatory uncertainties on so many levels, most companies are developing flexible strategies that will allow them to respond to changes in their operating environment despite the lengthy product lead times. Figure 6.1 presents a composite cognitive map of what seem to be the dominant strategies among agro-biotechnology companies.

It would be naïve to expect companies not to aim to maximise their profit potential but one interesting outcome from the perspective of the PITA project is the extent to which companies use the dialogue of sustainability, not simply to justify their actions, but also to guide their expectations of future impacts of policy on their business areas.

The social component of the sustainability dialogue is also important. Openness and flexibility determine a company's responsiveness to public policies and also its ability to cope with a complex operating environment.

In developing the new agro-biotechnology trajectories, companies are thus bringing all their resources to bear on the joint resolution of the interacting problems that link the main themes of Objectives 2 and 3 of the PITA project. As summarised in Figure 2.1, decisions made by managers in industry about type of product, level of investment and location of investment will have an impact at the European societal level on international competitiveness, employment and environmental benefits.

Figure 6.1 gives an overview of the type of strategy being envisaged by the major agro-biotechnology companies that are committed to remaining major players in the new life science trajectory for agriculture. The following subheadings are based on the concepts outlined in bold in Figure 6.1.

6.6.1 Developing whole crop strategies

This concept, in the centre of Figure 6.1, underlies the new approach to strategic planning already in existence in various stages of development in most of the MNCs studied. Strategies are being developed on the basis of particular crops, generally major crops traded globally as commodities, often in all the countries where they are grown. Under this strategy, companies will offer their customers (the farmers) a package incorporating both the seed and the technology to protect the growing crop and compete on the basis of the quality of the package, rather than on the basis of individual pesticides as in the past.

One tier down the map, the whole crop strategy involves linking solutions to pest, disease and weed problems, in each case involving a combination of chemical and biotechnology solutions. No alternative to herbicides was envisaged by any of the companies but, for pests and diseases, biotechnology could substitute for chemicals, partly but not entirely. For the latter two, therefore, companies would develop GM crops and back-up chemical protection as an integrated package. For weed problems, the herbicide and herbicide resistant crop would be developed as an integrated package and although there would not be the same degree of substitution involved, environmental criteria would be a major component in the design of the package. Also linking into the whole crop strategy, is the development of second generation products such as animal feed crops tailored to the nutritional needs of particular species and functional foods and nutraceuticals for human consumption.

There was also a strong feeling from the interviews that to succeed with this strategy, companies will need to have a strong base in agrochemicals and also a viable germplasm base, either in house or through alliances with seed companies. Some companies such as Bayer and BASF were late in reaching this conclusion and it is not yet clear that they will succeed in bringing in biotechnology and seeds strength to complement their undoubted strength in agrochemicals. However, that is the intention.

The other major influence feeding into this strategy, from the bottom of Figure 6.1, is pesticide regulatory policy and the stimulus it is creating to develop 'cleaner' pesticides with an improved environmental profile. It is a very important part of the company case that the new strategies will be an improvement environmentally on previous approaches and will contribute to sustainable development.

6.6.2 Contributing to sustainable farming systems

All companies included in the sample claimed to be making a contribution to sustainability of farming systems (top left hand corner of Figure 6.1). The whole crop strategies contributed to this by four different routes.

- By supporting high yielding agriculture, while at the same time reducing pesticide use and developing 'cleaner' pesticides, they avoid the need to take up land otherwise available for wildlife habitat and cause less environmental damage in the areas surrounding cropped land.
- All companies also refer to the need to feed an expanding world population, at least over the next 20 years and possibly beyond. In making such claims they have been heavily criticised by environmental groups who note that very little of the GM technology being developed in current company strategies is directed to developing country needs and indeed MNCs are attempting to claim intellectual property rights in crop varieties traditionally grown by poor farmers. There is now quite a bit of evidence that companies have accepted such criticisms and are beginning to offer free access to GM technology for developing countries.
- Whole crop strategies are also claimed to be contributing to ICM systems, partly through the availability of 'cleaner' pesticides and partly by using GM technology to reduce the amount of pesticide needed for effective crop protection. For most companies ICM implied merely the combination of pesticides and GM crops, perhaps also involving the engineering development of precision farming systems. Others (e.g. Novartis) went beyond merely technological interpretations of ICM and included the encouragement of natural pest controls, for example by crop rotation and the encouragement of pest predators.
- The fourth component of this strand of strategy was related to the reduced levels of pesticide use which result from the adoption of 'cleaner' low dose pesticides and the substitution of pesticides by GM solutions incorporated in crops. Avoiding the need to build a major chemical plant and to transport chemicals around the world was seen as a major environmental benefit, avoiding local environmental impacts from the chemical plant but also saving on the emission of greenhouse gases relevant to global warming.

6.6.3 Regaining consumer confidence in GM crops and foods

Regulatory solutions to the problem of public acceptance of GM crops (right hand side of Figure 6.1) were seen to have a role in regaining consumer confidence, including support for a revised European regulatory system (if it could provide the required element of certainty over a period of time) and also support for consumer choice through labelling. However the option which was expected by companies to be the most effective influence on the public was to develop products which customers will want to buy. Companies believed that one reason for the unpopularity of the first generation of GM products was that they only provided benefits for farmers; there were no apparent benefits at the consumer level. Functional foods and nutraceuticals were seen to provide the necessary element of public desirability and so were expected to change public attitudes. However there is as yet little evidence that functional foods will be the solution to the current set of problems and not the source of the next set of consumer problems (Tait, 2000).

6.6.4 Retaining long term viability and competitiveness for the company

The three major strands of strategic thinking outlined above were each expected to contribute to the viability and competitiveness of the companies included in the survey. The functional food component made an additional contribution to company competitiveness, if not to sustainable farming systems. By creating higher value crops in niche markets it will stimulate demand from farmers for more effective crop protection and so expand the market for new pesticides and GM crops. Thus functional foods, far from replacing the first generation GM products, will build an additional set of characteristics into them.

6.7 Policy influences on seed companies

The strategies outlined above and in Figure 6.1 are those described by the multinational agro-biotechnology companies. The purely seed companies were regarded by these companies as targets for take-over or, at best, for partnerships in their search for a viable seed base.

From the perspective of the seed companies themselves, they saw public policies and regulation to minimise pesticide use as signals to develop crop varieties with improved insect pest and disease resistance, either GM or non-GM. On the other hand they did not have the resources to invest on the same scale as the agro-biotechnology MNCs with their whole crop strategies.

Where seed companies had adopted GM technology, they were much more vulnerable to negative European public opinion in the short term than the agro-biotechnology MNCs. Not only were they struggling to compete on the same scale of investment but also they did not have the option of continuing to sell pesticides while waiting for the GM crop market to improve. If a significant part of their projected market was outside Europe, or if the European public opinion climate should improve rapidly they may be able to retain a major market role. However if neither of these two sets of circumstances applied, they would probably be even more vulnerable to take-over.

On the other hand, where seed companies were not involved in developing GM crops, they may be positively affected by current European public opinion which improves the market prospects for non-GM crops. Their long term prospects would depend on the future direction taken by public opinion, in Europe and globally.

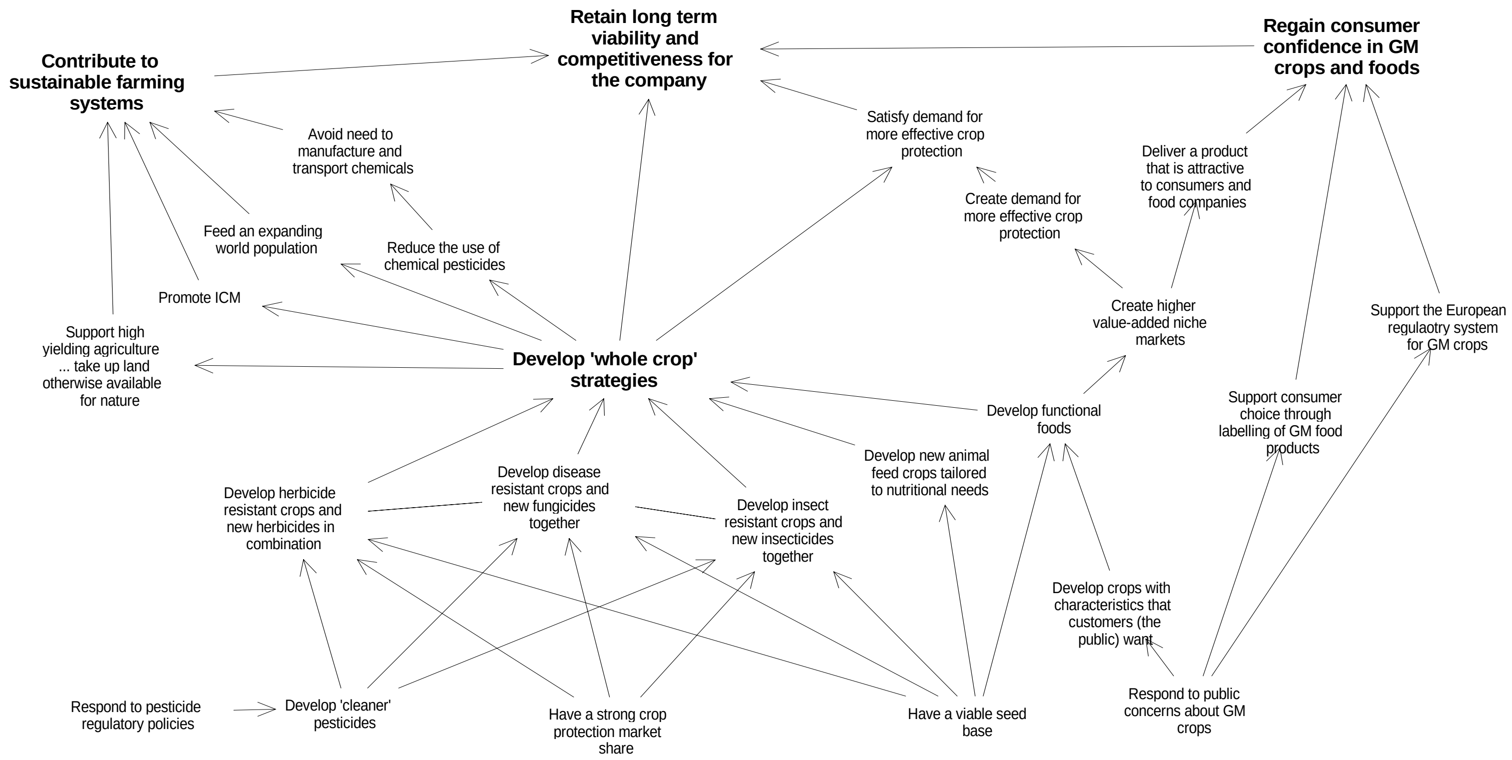

Figure 6.1 Agro-biotechnology strategies in response to policy, regulation and public opinion

7. Public sector research establishments (PSREs)

Major differences were found in the structure and functioning of PSREs among the different countries studied for the PITA project (see Annexes E1-E7). However, common tensions also emerged across the range of different national circumstances. All governments expect PSREs to contribute to national economic performance and to build links with industry, contributing particularly to the major private sector innovation trajectory involving biotechnology developments, described in section 4.3 . On the other hand PSREs are also expected to use their knowledge and expertise in the public interest, developing new techniques and products which have public benefits but are unlikely to be commercially attractive, and performing a public 'watchdog' role, highlighting and assessing areas of possible environmental and technological risk. PSREs across the EU are currently struggling to reconcile these two potentially conflicting sets of pressures.

7.1 The PSRE role in supporting industry strategies

The following private interest functions are common in varying degrees to most European PSREs:

- knowledge and technology transfer from basic to applied research in SMEs and MNCs;
- the setting up of spin-off companies to commercialise the results of fundamental research supported in the public sector;
- through the training of graduate students, to provide the pool of skilled labour needed by industry to expand its activities in any region.

PSREs have thus been encouraged to become more responsive to the needs of industry users and governments have tried to encourage more industry support for PSREs. In France, for example, research is concentrated in three main institutions, and although the majority of funding comes from the public sector, efforts have been made to encourage the PSRE contribution to economic growth and competitiveness (e.g. the Genoplante biotechnology initiative which is directed towards creating new economic possibilities) (see Annex E3).

The UK system on the other hand is more fragmented and cut backs in publicly funded 'near market' research have pushed some PSREs to re-orient their activities more strongly towards the needs of industry. Some have been privatised; others try to balance funding sources between industry and public funding from the EU and national government. The following points characterise the UK's funding of agricultural biotechnology: a pluralistic but highly concentrated funding system; science oriented as a means to encourage technological innovation; largely directed by the requirements of funding organisations (for research institutes but less so for universities); and with a high level of involvement of the private sector in management boards, councils and committees (Martin, 1998). As a result of such changes, direct links with farmers have suffered and industrial users have become more important. For example, the John Innes Centre have extensive IPR agreements which give them an important role in the R&D efforts of some companies.

Spanish PSREs have also been encouraged to develop industry links although they are still protected to a greater degree from commercial sector demands. Spanish PSREs contribute to both basic and applied research and, as in France, the focus is on small company start-ups. In the Spanish system, research organisations and funding sources are very varied and the degree of co-ordination between different bodies is low; public sector research functions independently from the economic and productive systems; there are conflicts between sectional, national and regional R&D policies; and there is limited experience of forecasting and evaluation, creating difficulties in defining priorities. (Muñoz *et al.*, 1999). In order to overcome these difficulties the Spanish government has launched a new R&D policy and many PSREs have been moved from their traditional ministry to the Ministry of Science and

Technology. These changes can lead to a shift in the objectives of research relations with industry and discourses on PSREs.

The large public research effort for agriculture and food in the Netherlands is related to the importance of agriculture in the economy. The core of public sector agricultural research is located at Wageningen University and the research institutes of the Agricultural Research Department (DLO). All PSREs receive funds from public sources and private industry but recently public spending has been level or declining while private funding has increased.

The German PSRE system includes universities and research institutes such as the Fraunhofer and Max-Planck Gesellschaft institutes. Over the last few years, the government has privatised some research institutes, reduced direct research funding, and shifted support to research contracts to increase efficiency. Research institutes tend to focus on applied research and the transformation of basic research into practical applications while the university system is more focused on basic research. Agro-biotechnology SMEs often have close links with PSREs, particularly universities, via joint research projects. Several research institutes, in particular BAZ and FAL, are responsible for providing government policy makers with neutral advice on agriculture, the environment, and agricultural biotechnology, although this advice is not always accepted.PSREs can make some research decisions independently of policy considerations but they are also required to conduct research of relevance to Government policy objectives.

7.2 The public interest role of PSREs

Public interest functions carried out by PSREs include:

- research and development on techniques with public rather than commercial benefits, e.g. ICM;
- developing and supporting risk regulatory and monitoring systems; and
- evaluating new technological developments from the perspective of potential risks and benefits.

The changes in the funding systems for PSREs which have directed activities more to commercial needs have led many observers to question whether PSREs can now be trusted to give impartial advice in the public interest.

Denmark has focused more strongly than some other countries on this public interest role for PSREs. The *Strategic Environmental Research Programme* was established as a result of a government initiative, following an international evaluation of environmental research in 1989. The evaluation stressed that “Danish environmental research was spread across a large number of smaller research environments which only occasionally co-ordinated their activities, and that the environmental research varied strongly in both quality and depth”. The aim of the Research Programme is to support *strategic* research, i.e. “research [that] would contribute to an operational application of new and existing knowledge within the political, administrative, economic and social decision-making processes in the area of the environment”.

7.3 Reconciling conflicting roles in PSREs

The current structure and role of PSREs perhaps limit the extent to which they can contribute to discussions about the risks of new technologies. As the precautionary principle becomes more important in risk assessment in European agriculture the role of public sector research becomes more complex. Although public sector researchers have identified some potential risks, and governments have begun to involve PSREs in risk assessment, PSRE programmes have not in general reflected the importance of risk assessment in the debate about new technology in agriculture. This may be an indication of government ambiguity about the extent of public sector involvement in risk assessment, and also in some cases a rather narrow approach to promotion of national competitiveness and new technology.

In the Netherlands, Government spending on applied research is now treated separately from private sector spending so that government can have more influence on how public funds are used. It is recognised that public sector interests are not necessarily the same as private sector interests, and, in addition, government spending on applied research has become more difficult to legitimise politically (Diederen, 1998).

The French PSRE report (Annex E3), for example, comments that a major weakness stems from the relations between laboratory science and real life situations. The norms currently enforced, for example on water quality, do not result from solid risk assessments and there is a need for better prediction of effects related to the dynamics of complex systems, which requires large scale experimentation as well as careful monitoring. PSREs are responsible for this area and need to develop such competencies in order to prevent potential damage or inappropriate decisions (Gray and Graham, 1997). New systems are being introduced in INRA with the aim of facilitating efficient management of its multiple roles.

Increased private sector involvement in PSREs thus poses some problems for PSRE involvement in risk analysis at a time when trust in government monitoring of new technologies and associated risks is low.

8. Small and medium enterprises (SMEs) in agro-chemicals, seeds and biotechnology.

During the 1980s and early 1990s, biotechnology was expected to herald a new era in agro-chemical and seed development (Oakey et al, 1990, Orsenigo, 1989), following the same pattern as the IT revolution, with new small firms forcing the pace of change and forging new trajectories. This might have allowed SMEs to create new markets based on more environmentally sound biotechnology based products. However, as indicated above, control of the evolution of agro-biotechnology has remained firmly rooted in MNCs. Market and industry structures, lack of venture capital, high development costs and regulatory hurdles have prevented these trends from emerging (Chataway and Tait, 1993). Uncertainty surrounding public attitudes to biotechnology has compounded these problems for SMEs with the result that the sector is very small indeed in comparison with the scale of MNC activity and many firms are struggling to survive.

Annexes D1-D7 describe in detail the agro-chemical, seeds and biotechnology-based SME sectors in the countries surveyed and give an overview of innovation strategies and policy influences.

8.1 Agro-chemicals

As described above, a small number of MNCs dominates the research and development of agrochemicals in Europe. On the other hand, formulation, generic production, bottling and distribution are often carried out by SMEs. For example, in Denmark, with the exception of Cheminova which has more than 1000 employees and cannot be characterised as a SME, the main activity of most SMEs is the import and sale of pesticides or the manufacture of fertilisers. In the Netherlands, 19 companies account for 95% of domestic pesticide sales but only Aseptafabriek BV is an independent SME which registers, tests and sells pesticides developed by other companies. Two other SMEs, ProAgro and Luxan, are fully owned by larger companies although they are able to develop independent strategies. In Spain 90% of pesticide production is in the hands of MNCs, and SMEs mainly formulate new products based on active substances whose patent has expired or been given up by big corporations. One SME, Industrias Químicas del Vallés, identified as innovative, has registered an active substance and synthesises new phytochemical substances.

There were two areas in which agrochemical SMEs were able to develop innovation strategies. Some were developing IPM strategies as a consultancy service and where these also involved new products based on bio-pesticides (see particularly Annexes D1 and D3) this was providing a potential growth area for SMEs (Arundel, 1999). Focusing on market niches that were not large enough to be attractive to MNCs, some SMEs were developing products specific to small scale crops.

8.2 Seeds

Seed producers have traditionally been small family-owned companies, which supplied local markets with new varieties adapted to the agro-ecological features of the area. Now biotechnology is having a major influence on the industry, opening up the possibility of obtaining new varieties with additional characteristics and attracting the attention of the agro-food and agrochemical industries (Bijman, 1999b). Despite the purchase of many seed companies by MNCs and the merger of others, the number of companies is still higher than in the agrochemical sector.

The strategies characteristic of these companies and their position in the market depend on the kind of seed they produce. MNCs lead in major crops (maize, soya, cotton, etc) where larger economies of scale can be found and where biotechnology has so far been concentrated. There is more competition between MNCs and SMEs in horticultural crops although as noted previously, MNCs are generally withdrawing from niche markets.

Seed markets are different in each of the countries studied. The majority of independent SMEs are in the Netherlands and France. The seed industry in the Netherlands is large compared to other countries and has a strong international orientation. There is a long tradition in seed production and the country has a leading position in horticultural seeds and potato seed crops. Many of its SMEs have expanded and now operate in other European countries so that their market share is quite high. However, the largest vegetable seed companies in the Netherlands are now subsidiaries of foreign multinationals. In agricultural crop seeds one company is among the top five seed companies in the world (Advanta) and one company, despite its relatively small size, is a global player (Barenbrug).

France has approximately 100 companies involved in seed research and development, in 5 categories: independent and family owned, co-operative owned, joint ventures, subsidiaries of foreign companies and subsidiaries of pesticide companies.

Spanish seed companies are mostly family businesses that specialise in meeting the needs of local markets. There are many seed multiplying companies but relatively few carry out research, which is traditionally done by public researchers. Semillas Fitó (horticultural and garden seeds), Semillas Battle (garden seeds), Semillas Ramiro Arnedo (horticultural seeds) and Agrosa Semillas (cereals seeds) are important SMEs in the national market.

In Denmark most national companies multiply seeds or import them on a licence basis. A few small companies are independently owned but they are not able to invest substantial amounts of money in long-term research and development. One company, DLF-Trifolium, has a market share of over 70 % in the Danish home market, a dominant position as a supplier of grass and clover seeds for the European market, and has the capacity to develop and market its own traits.

In the United Kingdom only a few independent companies survive developing new varieties. One highly innovative company, Elsoms Seeds Ltd, has some 80 employees and is active in several government-funded LINK research projects and uses assisted breeding techniques.

8.3 Biotechnology and innovation promotion policies

A number of agro-biotechnology SMEs emerged in the late 1980s and early 1990s but few have remained as independent entities and the rate of new start-ups declined throughout the 1990s. The recent increase again in the number of biotechnology based SMEs in Europe is probably linked to European governments’ promotion policies. Most of the new firms are in the pharmaceutical sector which has a different market and industry structure and regulatory regime and also higher profit margins, and so provides a more favourable environment for SMEs. The uncertainty surrounding the European public response to biotechnology innovations exacerbates an already difficult context for agro-biotechnology SMEs and interviewees in the PITA project also mentioned as negative influences unhelpful tax codes, rigid labour markets and inadequate technology transfer infrastructure, particularly in the agro-chemicals and seeds areas. (Schitag *et al.*, 1998; Bijman, 1999a and b; Licht and Legler, 2000).

In the UK two research programmes support the creation of new companies: LINK supports collaborative partnerships between industry and the research base; and SMART, a Department of Trade and Industry initiative, provides financial assistance for the development of pre-competitive innovative technology. In The Netherlands the Ministry of Economic Affairs has initiated the 45 million Euro Life Sciences Action Programme to help biotechnology start up firms. Belgium, Switzerland and Sweden also have enhanced promotion programmes for biotechnology.

In Germany, from 1997, the Federal Government implemented the BioRegio-Competition project, which supports regional clusters of expertise in biotechnology in the Rheinland, the Rhein-Neckar triangle and Munich, each receiving DM 50 million. As a result 150 new biotechnology businesses were set up by 1998 and over DM 560 million of private capital was invested in biotechnology in these regions. However, most of the resulting SMEs are micro-companies with fewer than five employees, emerging from universities or PSREs. Their main activity is research and development for other companies since most do not have the capacity to take products through to the market stage. Also, many have been purchased by MNCs or have formed alliances with them, or are part of joint ventures. Thus, there are in practice few independent agro-biotechnology SMEs, even in the countries where most biotechnology companies are located (UK, Germany and the Netherlands).

8.4 Policy impacts on SMEs

Detailed assessments of the impact of policies on SMEs in agro-chemicals, seeds and biotechnology are contained in Annex D1.

In the case of agrochemicals, the few independent SMEs are facing a major challenge to adapt their products to the new requirements of EC Directive 91/414, which increases the costs of registration of new products and may lead to withdrawal of older off-patent products. The strategy adopted by these companies is to seek new environmentally-beneficial products to be used with IPM systems and to search for niche markets where they can avoid competition with MNCs. In this sense bio-pesticides offer opportunities, in niche markets and as a complement to agrochemical products.

In the seeds sector, the challenge facing independent SMEs is the introduction of biotechnology into their core competencies. Their strategy is to concentrate on developing a few crop varieties for local markets, targeting their R&D investments on pest and disease resistant varieties in response to environmental and agricultural policies and agro-food industry demands for the reduction of pesticide usage in agriculture. Since the GM crop market remains uncertain and SMEs do not have the resources to cope with this uncertainty, most of them use traditional breeding techniques, increasingly also involving assisted breeding.

In the biotechnology area, because of constraints such as the uncertain regulation of GMOs, the lack of external funding, public rejection of GMO products and hence the uncertain market, SMEs mainly carry out R&D for large companies. Their strength lies in alliances and networks with PSREs (to gain access to the latest scientific advances) and with MNCs (to ensure that their products respond to market demands and to provide a buffer against uncertainty). Independent SMEs try to strengthen the economic exploitation of their technologies rather than to broaden the scope of their activities, and also to find niche markets left by MNCs. In that sense, solutions to environmental problems are seen as a market opportunity for SMEs.

Public policies have had an important impact on the activities of SMEs, especially Directive 90/414 and environmental policies in agrochemical companies, IPR in seeds companies, and GMO legislation and STI policies in biotechnological companies. It is difficult to predict the influence of public policies on the innovative role and competitiveness of SMEs, given that market-related factors have a more direct impact on them.

Thus, while science and technology policies have positive impacts on SMEs in all areas they are contradicted by constraints posed by other policies. Other factors such as industry and market structures and public opinion pose additional obstacles. The impact of environmental policies is mixed – they were considered a constraining factor by many firms interviewed, but there is also the possibility in agro-chemicals that regulation may create niche market opportunities for SMEs. In seeds and biotechnology, regulation is seen to be pushing SMEs in new directions based on consideration of environmental impact.

9. Employment

9.1 Employment and competitiveness

Advanced biotechnology, based on genetic engineering, provides new technical opportunities for developing seeds and plant protection products (PPPs) such as pesticides. These opportunities can potentially influence employment throughout the agro-food chain, from the suppliers of agricultural inputs to food processors and retailers. The ability of European seed and PPP firms to take advantage of advanced biotechnology could also influence their global competitiveness.

Advanced biotechnology is generally viewed by European policy makers as a new technology that will have a positive effect on employment. This optimistic perspective is based on an increase in employment among small dedicated biotechnology firms (DBFs) and in the pharmaceutical sector. Nevertheless, although advanced biotechnology can be used in both agriculture and pharmaceuticals, the former could have a greater impact on employment (the pharmaceutical sector accounted for only 1.6% of total European manufacturing employment in 1992, compared to 9.6% for food processing (OECD, 1998)).

This chapter qualitatively assesses the effect of innovation in the seed and PPP sectors on employment and competitiveness, covering direct employment effects (within the firm that develops the innovation) and indirect effects (among suppliers, users and competitors). The results largely confirm Watanabe's (1985) prediction that the direct employment effects of agro-biotechnology are likely to be marginal and limited to R&D and production in a 'small number of highly capital- and science-intensive establishments in industrial countries'. The indirect employment effects are likely to be larger, but many of the innovations should reduce aggregate employment in the agro-food chain. In contrast, higher value-added quality traits could lead to employment increases, although public opposition in Europe to GM food could limit the development of quality traits to non-GM techniques.

In addition to a literature review, information has been obtained from analyses of relevant questions in previous surveys from Europe and Canada, interviews with 14 of Europe's largest seed and PPP firms, a new survey of European seed and PPP firms, and an analysis of the European database on field releases of GM crops.

9.2 Main employment trends in the agro-food chain

The seed and agrochemical sectors are part of an agro-food chain that runs from the suppliers of agricultural inputs to the final consumers of agricultural products, as shown in Figure 9.1. The innovative activities of firms in the seed and PPP sectors can influence employment patterns throughout the food chain, with the possible exception of retailers. Retailers can play a major role, however, by influencing agricultural prices and the types of crops that are grown.

9.2.1 Background employment trends

The effect of innovation in the seed and PPP sectors must be seen in the perspective of a long-term decline in the share of agriculture and manufacturing in European employment, due to labour-saving innovation and a relative fall in demand for agricultural and industrial products compared to services. Between 1985 and 1997, the share of the workforce in agriculture declined in all member states of the EU by an average of 35.3%, from 54.1% in Spain to 17.4% in the UK (OECD, 1999), although total agricultural output increased by 9%, from 224.9 billion to 245.2 billion US (1990 dollars).

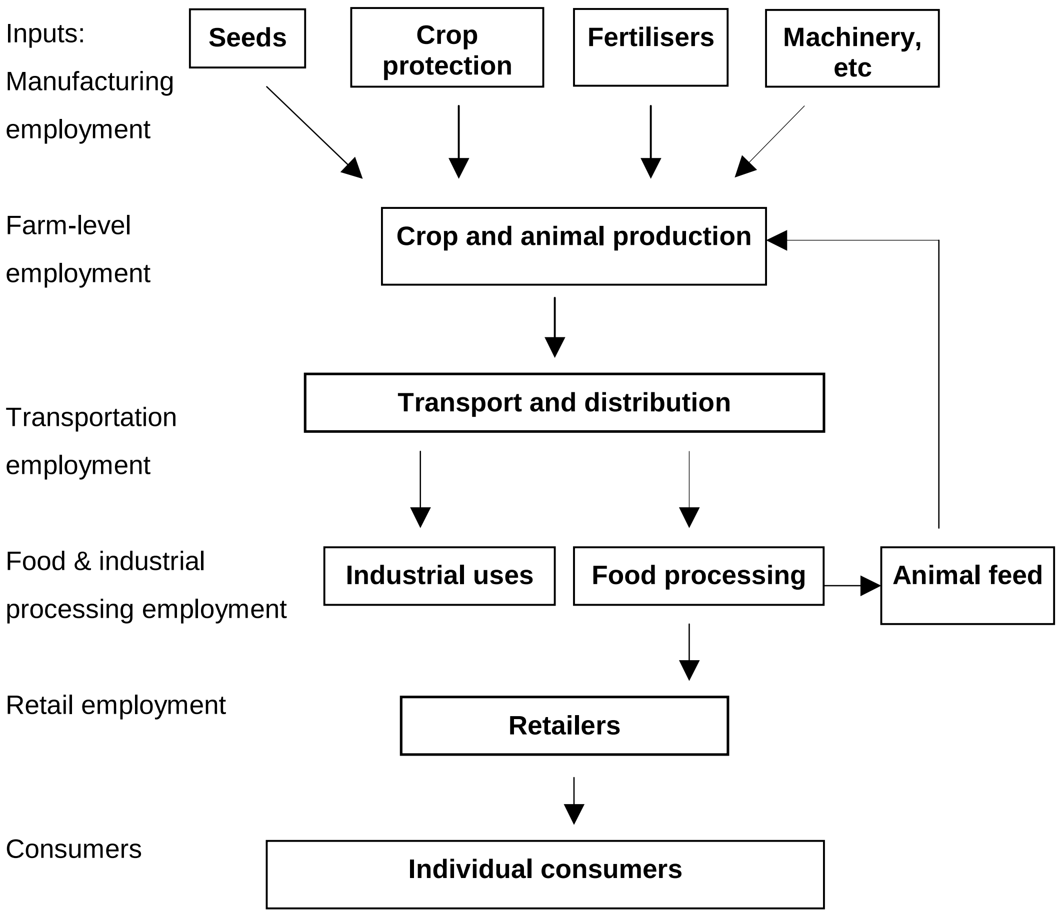

Figure 9.1 Agro-food chain

Slow population growth in the EU places a constraint on the growth of the European market for seeds and PPPs so that employment growth in these sectors will depend on exports. Zeneca Agrochemicals predicts that the global market for agrochemical products will increase from 30 billion $US today to 75 billion in 2020, largely from growing demand in Asia and Latin America. Market growth, however, depends on an increase in average incomes in the developing world, leading to more demand for animal feed for meat and dairy production (OECD, 2000). The global market for seeds is approximately 5 billion $US.

9.2.2 Agro-biotechnology employment

An assessment of the direct employment effects of innovation requires a baseline estimate of the number of jobs that involve agro-biotechnology in some way. Data from Ernst and Young (1997) suggest that there were 5,625 jobs in Europe in entrepreneurial agro-biotechnology firms in 1996. This is an underestimate, since only DBFs with fewer than 500 employees are included, whereas the use of biotechnology in Europe is concentrated in large firms. Conversely, a EuropaBio study vastly overestimates employment by assuming that all employees in firms that use agro-biotechnology at any point are in biotechnology 'dependent' jobs. This method estimates 588,000 agro-biotechnology jobs (Burke and Thomas, 1997).

A more accurate method for estimating agro-biotechnology employment was used in two surveys by Statistics Canada in 1996 and 1997. These estimated that approximately 1% of food processing and agro-chemical employees were involved with biotechnology in some way in Canada. This rate, plus the data from Ernst and Young and the survey results for PPP and seed firms, suggests that there were approximately 50,000 agro-biotechnology jobs in the European Union in the late 1990s.

9.2.3 Skill levels

Although most agro-biotechnology innovations are unlikely to alter the long-term decline in employment in the agro-food chain, advanced biotechnology innovations could shift employment towards more skilled jobs that are traditionally better paid. In Canada, 43.2% of employment-weighted agro-food firms reported that the adoption of biotechnology increased skill requirements, compared to only 1% that reported a decrease (Arundel and Rose, 1999). An increase in activities in foreign markets is also most likely to increase European employment in R&D and management.

9.2.4 Labour-saving innovation

Survey data from Canada and the European Community Innovation Survey show that food firms attach a high importance to reducing direct and indirect costs. These factors limit the ability of seed and PPP firms to increase their prices to cover the development costs of value-added innovations. For example if the price of high lysine corn for poultry feed is too high, feed processors can add lysine from industrial fermentation demonstrating one of the basic problems of agro-biotechnology innovation: there are competitive alternatives to many agro-biotechnology products (Arundel, 2001) which, combined with low switching costs, will limit the profitability of many innovations.

The large number of mergers in the seed and PPP sectors in the last decade will also reduce employment. As an example, the 1999 merger of Rhône-Poulenc and AgrEvo to form Aventis is expected to reduce employment by 3000 to 4000 jobs, with the closure of an R&D centre in the UK and a European pesticide manufacturing plant .

9.2.5 Policy, prices and employment

Farm-gate prices for agricultural crops are strongly influenced by government policies. The OECD (2000) predicts that CAP reform will increase European wheat production and decrease the output of oilseed, maize and coarse grains. Although individual seed and PPP firms could gain or lose employment, it is unlikely that crop shifts will have a detectable effect on aggregate employment in the agro-food chain.

Conversely, a decline in aggregate price subsidies due to CAP reform or world trade agreements is likely to reduce agricultural output and employment among input suppliers, on the farm and in transport and distribution. Current levels of agricultural employment are not sustainable without subsidies, as shown by a 10.7% decline in the gross value-added of European agricultural output (at market prices) between 1990 and 1997. One cause of the decline is an increase in input costs (fertilisers, pesticides, maintenance, and animal feed) which has largely been met by increasing subsidies from 15.4 billion to 36.7 billion Ecus.

Green agricultural policies to pay farmers for land stewardship could reduce the effect of a reduction in price subsidies on farm employment but they are less likely to support employment in the seed and PPP sectors. One exception is fiscal measures to encourage farmers to adopt environmentally beneficial inputs such as phytase-reduced feed corn.

9.3 Innovation strategies and employment

9.3.1 Seed firms

Five options for innovation in plant breeding (DG Agriculture, 2000) could affect employment through the agro-food chain (with the exception of retailers where no employment effects are expected) (see Table 9.1). The estimates assume no increase in exports, no change in current subsidy levels and price inelastic domestic demand for agricultural products except for some quality characteristics.

Table 9.1 Employment effects of innovation in the seed sector

	Employment effects in the agro-food chain					
Option	Input suppl	Farm level	Trans. & distr.	Food proc.	Industr proc.	Overall
1. Increase yield per hectare	--	↓	--	--	--	⇩
2. Increase yield per unit inputs	↓	--	--	--	--	⇩
3. Reduce risk to farmer	↑	--/⇩	--	--	--	--
4. Input switching (no yield effect)	⇧/⇩	--	--	--	--	--
5. Enhanced quality characteristics	↑/↓	⇧	↑	--/⇩	--/⇩	⇧/↑

↑ = relatively strong positive increase; ⇧ = weak increase; ↓ = strong decline; ⇩ = weak decline; --/⇩ = no effect to weak decline; -- = no effect; ⇧/⇩ = substitution effects.

Innovation options in the seed sector, except for quality traits, are likely to decrease overall employment, with shifts in employment from one firm to another from substitution effects. Quality traits could increase aggregate employment by increasing the value-added of agricultural output. Quality traits with industrial applications, such as the use of plant oils for lubricants or biomass for energy production, will shift employment from industry to the agro-food sector. In addition, quality traits that permit European production to replace imports will increase European jobs. An example is high lauric acid rapeseed which could replace imported palm and coconut oil in detergents and lubricants.

Quality traits require identity preservation, or the ability to separate improved crops from other varieties throughout the agro-food chain, and this will increase employment in transport and distribution. Quality traits will also require an increase in crop prices to cover identity preservation costs, between 6% and 17% of the farm-gate price, depending on the crop (DG Agriculture, 2000). Farm level employment could also increase slightly if the price paid for improved crops increases and if farmers can capture part of the price increase.

Another trend identified in the interviews is to concentrate breeding activities on a few core crops, usually the major commodity crops such as maize, grains and oilseeds where large market sizes increase potential profits and provide a greater chance of recouping development costs. This trend is part of a general globalisation of the seed sector but success in this strategy depends on the ability to insert high value-added traits into elite varieties that are adapted to local conditions in Europe, North America, Latin America and Asia. Given the need to develop local varieties *in situ*, the positive employment effects among European-owned firms are likely to be limited to high-skilled jobs in management, administration and research.

A limiting factor on the employment effects of innovation is the share of specific crops in total crop values and cultivated hectares in Europe. As shown in Table 9.2, the main GM target crops for Europe account for only 16.3% of the total crop value in 1997 and for 10.1% of the total hectares under cultivation.

Table 9.2 EU 15 crop values and hectares under cultivation

	1997 crop values (Million Euros)	Per cent	1997 hectares under cultivation (000)	
Main potential GMO crops	17,110	16.3%	13,617	10.1%
Maize	*4,128*	*3.9%*	*4,387*	
Potatoes	*4,227*	*4.0%*	*1,539*	
Sugar beets	*5,657*	*5.4%*	*2,041*	
Oilseeds	*3,098*	*3.0%*	*5,650*	
Cereals (excl. maize)	17,143	16.3%		
Vegetables, fruits, and vine crops	55,110	52.5%		
Other crops	15,567	14.8%		
Total	**104,930**	**100.0%**	**134,631**	**100.0%**

Sources: OECD (1999), DG Agriculture (2000b).

The effect of GM crops on employment in the agro-food chain is likely to be comparatively small until GM techniques can be applied to crops such as wheat (16.3% of crop value), and vegetables, fruits, and vines (over half the total value, of which many of these crops have very small markets in volume terms, although higher in value). The employment effect of advanced biotechnology will therefore depend on the incentives for firms to apply genetic engineering to small-market crops. This will depend on the cost of using GM techniques falling over time.

An analysis of the European field release data for GMOs, available from the EC Joint Research Centre gives a measure of the shift by seed firms into GM quality traits. Field trials can begin two to three years after the start of a project to develop a new variety and run almost until the variety is ready for commercialisation. Given an average of 10 to 12 years to develop a new seed variety, the field trial data show what might reach the market within two to seven years.

Figure 9.2 gives the percentage of all trial-trait combinations for each of five major trait classes. A two-year running average is used to smooth out annual differences in the number of trials, which peaked in 1996 at 369 trials and declined to 285 in 1999.

Over 40% of all field trials during the 1990s were for herbicide tolerance, followed by pesticide resistance (about 30%). The share of quality traits increased between 1991 and 1997 but has since remained relatively stable (about 20%). Yield traits were least important over this period.

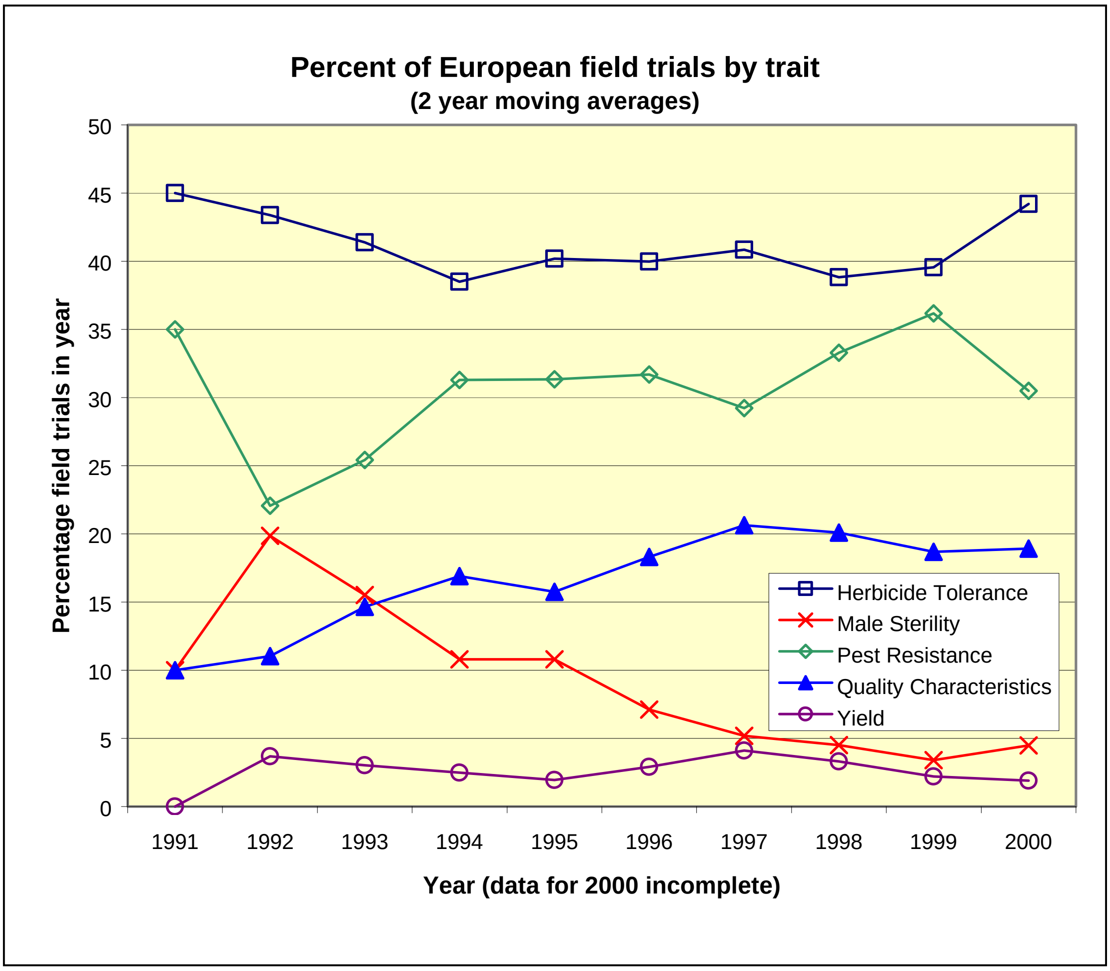

Figure 9.2

These data do not suggest a major shift in the near future in the types of GM crops coming onto the market. It is possible that most of the research on quality traits has not yet reached the field trial stage which would imply that a shift to marketing higher value-added quality traits, and any positive employment effects, are over five years away.

9.3.2 PPP firms

Three main innovation options are being used to develop plant protection products (see Table 9.3). For chemical pesticides the long term trend is towards stronger pesticide regulation to reduce environmental and health risks. This could reduce aggregate employment if total pesticide use falls; this trend may be counteracted by developing environmentally improved pesticides. Environmental regulation to encourage their use, combined with patent protection, would permit the manufacturer to charge a premium price. Substitution effects should occur where chemical pesticides compete against pest-resistant crop varieties, bio-pesticides and IPM.

The second option includes herbicide tolerant crops where the pesticide and the seed are sold as a package. A new development involves seeds designed to respond to chemical switches that turn selected traits on or off, as needed. In future, crop-PPP packages could be based on quality traits. The third option, bio-pesticides, forms only a minor part of the innovative activities of PPP firms and competes with the other options.

Table 9.3 Employment effects of innovation in the PPP sector

Option	Employment effects: Input suppl	Farm level	Trans. & distr.	Food proc.	Industr proc.	Overall
1. Chemical pesticides	⇧/⇩	--	--	--	--	--/⇩
2. Chemical-crop combinations	↑/⇩	--	--	--	--	⇧
3. Bio-pesticides	⇧/⇩	--	--	--	--	--

↑ = relatively strong positive increase; ⇧ = weak increase; ↓ = strong decline; ⇩ = weak decline; --/⇩ = no effect to weak decline; -- = no effect; ⇧/⇩ = substitution effects.

9.4 Survey of seed and PPP firms

The effect of different methods of developing seeds and PPPs on employment and competitiveness was further investigated in a one-page fax survey. Questionnaires were sent to all commercial seed and pesticide firms in the UK, Spain, France, Germany, the Netherlands and Denmark between May and July of 1999. The adjusted response rate was 72% for both seed and PPP firms. In total, 99 responses were obtained from firms that develop new seed varieties and 56 responses were obtained from firms that develop PPPs.

The survey obtained data on the type of technology in use, total employment, the number of development employees (R&D plus field testing, regulatory compliance, and research management), the expected change in development staff by 2002, non-EU exports, and sales. The question on employment change was limited to development staff because the respondents, mostly R&D managers, could probably give a reasonably good answer, whereas they could have found it difficult to answer a question on changes in total employment. A key survey result is an estimate of the importance of genetic engineering for developing new seed varieties.

9.4.1 Seed firm results

The survey results assign all seed firms into one of three technology classes, depending on the most advanced technology they use to develop new seeds: genetic engineering; assisted conventional breeding (using techniques such as DNA markers and gene sequencing developed for genetic engineering); and conventional or classical plant breeding. The number of firms that used each technology in 1999 and planned to use them in 2002 are given in Table 9.4. Firms that use genetic engineering (see first row of the table) can *also* use assisted conventional or conventional breeding. Firms that use assisted conventional breeding (see second row) can also use conventional breeding, but none used genetic engineering. The third row gives the percentage that *only* used conventional breeding technology.

One-third of the firms (68.4% of total employment among the 99 firms) used genetic engineering in 1999 to develop seed varieties. By 2002 the percentage of firms using assisted conventional breeding should increase to 30.6% from 23.2%, while the percentage using genetic engineering should increase to 49%.

Table 9.4 Current and planned users of each seed development technology

Most advanced	Current use (1999)			Planned use (2002)		
technology in use	N	% firms	% employees	N[1]	% firms	% employees
Genetic engineering	33	33.3	68.4	48	49.0	79.5
Assisted conventional	23	23.2	18.1	30	30.6	14.0
Only conventional	43	43.4	13.5	20	20.4	6.5
Total	**99**	**100%**	**100%**	**98**	**100%**	**100%**

1: One firm did not provide data on planned use.

The firms were also asked to estimate the percentage of their total development budget that was spent on each technology in 1999 and the expected share for 2002. Only 10.2% of the total development budget among the 99 firms was spent on genetic engineering in 1999, compared to 16.5% spent on assisted conventional and 73.4% spent on conventional breeding. The share spent on genetic engineering is expected to increase to 14.7% in 2002, assisted conventional to 26.2%, and the conventional share to decline to 59.1%.

Conventional plant breeding can also be used to test the stability of genetically-engineered seed varieties. In contrast, almost all of the spending on assisted conventional breeding is used to develop new plant varieties. A maximum estimate of the 1999 share of genetic engineering in developing, rather than testing, new varieties can be obtained by assuming that only the two most advanced techniques are used to develop new seeds. Under this assumption, 38% of the 1999 budget for developing new seeds could have used genetic engineering.

Table 9.5 gives employment estimates by the most advanced technology in use. Overall, the results estimate that there were 19,161 employees of seed firms in 1999 in these six countries, of which 27% were involved in development. The number of development employees is expected to grow by 7.4% over the three years up to 2002. There are no statistically significant differences in the expected growth in development employees by the most advanced technology in use.

Table 9.5 Seed firm employment by most advanced technology currently in use

Most advanced technology in use	1999 total employees	1999 total development employees	Estimated extra development employees in 2002	% increase in development employees
Genetic engineering	9,405	2,308	174	7.5%
Assisted Conventional	2,488	961	54	5.6%
Unassisted conventional	1,853	404	43	10.6%
Survey total	*13,746*	*3,673*	*271*	*7.4%*
Entire population Est.[1]	*19,161*	*5,120*	*378*	

1: Extrapolation to the entire population of seed firms, based on the assumption that the distribution of employees is identical among an estimated 39 eligible firms that did not respond to the survey.

The figure for mean sales per development employee does not differ significantly, for the most advanced technology in use, from the average of 721,000 Euros. Firms that use assisted conventional breeding export 37.1% of their output to non-EU countries, which is significantly above the average of 24.6%. The export rate is 20.2% for firms that use genetic engineering, probably because many of these are large firms that serve export markets from their foreign subsidiaries.

9.4.2 Pesticide firms

Unlike the situation for seeds, one class of pesticide is not technically more advanced than another, although chemical-crop combinations require expertise in both chemistry and biotechnology. Almost all employment (90.6%) in the PPP sector is in firms that develop chemical pesticides, although many of them develop other types of pesticides. Chemical pesticides dominate both the 1999 and 2002 budgets, although the share for chemicals is expected to decline from 87% in 1999 to 81.7% in 2002. Chemical-crop combinations is the only option likely to increase value-added and employment; and it has the greatest expected increase in research expenditures, from 7.0% in 1999 to 11.9% in 2002. The share for bio-pesticides is expected to increase slightly from 6.0% to 6.4%.

The number of development employees is expected to increase by 3.3% (less than half the expected increase of 7.4% for seed firms) as shown in Table 9.6. The number of development employees among firms that only develop chemical pesticides is expected to increase by 0.7%, followed by an increase of 5.2% among firms that develop chemical/crop combinations. In contrast, the number of development employees is expected to increase by 26.6% among firms that develop bio-pesticides, although from a very small base. These firms only account for 5.8% of current development employees.

Table 9.6 Pesticide firm employment by type of pesticide

Pesticides developed by firm	1999 total employees	1999 total development employees[1]	Estimated extra development employees[2] in 2002	% increase in development employees
Only chemicals	6,566	1,699	12	0.7%
Bio-pesticides	1,299	184	49	26.6%
Chemical + chem/crop	5,108	1,004	52	5.2%
All three types	896	288	-8	-2.7%
Survey total	*13,869*	*3,175*	*105*	*3.3%*
Entire population Est.[1]	*19,318*	*4,442*	*146*	

1: Extrapolation to the entire population of pesticide firms, based on the assumption that the distribution of employees is identical among an estimated 22 eligible firms that did not respond to the survey.

The average percentage of pesticide sales from non-EU exports is 55.3%, over twice the rate for seeds, which reflects the ability of PPP firms to serve foreign markets from EU manufacturing plants and also the higher value-added in pesticides compared to seeds. The type of pesticide manufactured by the firm does not affect the export rate or the average sales per development employee, suggesting that this factor does not confer any unique competitive advantages.

9.5 Conclusions

There were approximately 50,000 direct jobs in agro-biotechnology in the EU in the late 1990s (about 0.2% of total EU manufacturing employment). Most of the employment impacts of agro-biotechnology will be due to indirect effects throughout the agro-food chain, where total employment in food processing alone is over 3 million.

Of the five innovation options available to seed firms, quality traits have the greatest potential to increase employment in the agro-food chain, through an increase in value-added, the development of new markets for industrial inputs, and import substitution. The potential for seed firms to develop quality innovations is constrained by the cost of identity preservation, competitive alternatives and low costs to switch to alternatives for farmers, food, and industrial processors. The field test data show that there has been no increase over the past five years in the share of quality traits among trials suggesting that it could be at least five years before GM quality traits begin to reach European markets and affect employment.

All five innovation options could lead to an increase in European employment if European seed firms succeed on foreign markets, where most future growth lies. Most of the increase is likely to be in skilled jobs in research and management since seeds are tested in their market area but the direct effect on seed firms is likely to be small, with only an additional 378 development jobs expected between 1999 and 2002. Many of these gains could be counterbalanced by job losses as a result of mergers.

Employment in the PPP sector is most likely to increase through the development of chemical-crop combinations. It could also increase through the adoption of quality-enhanced seeds, which could encourage farmers to use more PPPs to protect the higher value crops. An additional 146 development jobs were expected in the PPP sector by 2002.

Unfavourable market and regulatory conditions for GM crops in Europe could reduce the competitiveness of European seed firms and the potential for employment gains. However, the survey results show that these concerns are unfounded in the short term. Only 10% of total investment in developing seeds is for genetic engineering and this reduces the exposure of European firms to poor markets for GM crops. At the same time, European seed firms are rapidly developing capabilities in genetic engineering and related technologies used in assisted conventional breeding. Also, firms that currently use genetic engineering do not expect the number of their development employees to grow more quickly than other firms, which suggests that non-GM methods are still competitive. In addition, there are no differences in the average sales per development worker by the most advanced type of technology in use, one measure of the efficiency with which firms can translate development costs into sales. Nor are export rates to countries outside of the EU higher among firms that use genetic engineering compared to firms that only use assisted conventional or classical breeding methods.

These results show that European seed firms are rapidly building competencies in genetic engineering, while hedging their bets and they should be able to remain competitive over the sort term in either a favourable or hostile environment towards GM crops (Arundel *et al*, 2000).

10. Conclusions and policy implications

Section 4.2 of this report described our integrated analysis of the policy environment and our assessment of its potential impact on industry, developed before carrying out the interviews. This section revisits our initial analysis in the light of the industry interviews and explores the potential implications of our findings for industry and for policy makers.

10.1 Recent policy developments

Since 1997, when this project was conceived, the European policy and regulatory environment has been going through a period of extreme turbulence, particularly in the context of GM crops, with potentially major impacts on the companies we have been studying and on the European environment. Public concern about GM crops has been increasing rapidly in most European countries, most notably in the UK and France (Gaskell et al., 2000). The policy responses to these concerns across European countries have become increasingly out of step with the intentions of EC Directives and the prospect of EU harmonisation of biotechnology policies is receding (Levidow, Carr and Wield, 2000). At the same time national governments and the European Commission have been responding to public concerns with a variety of new policy and regulatory initiatives and international negotiations have also been affected.

10.1.1 Global developments

At the global level the risk regulation of GM crops has been an important influence on the Millennium Round of WTO talks, and trade in GM crops and foods has become a focus for potential dispute between Europe and other regions of the world. The agricultural agenda for these talks has been shifting to include non-food concerns and multifunctionality of farming systems (OECD, 1998). However, public concerns about risk regulation have remained, including sustainability of food production systems, the increasingly rapid pace of technological innovation and the power of multinational companies to control trade in agricultural commodities (Tait and Bruce, 2000).

The major policy issues contributing to these developments have been trade liberalisation, the role of the precautionary principle in risk regulation, evaluation of the environmental impact of GM crops, the involvement of a wide range of stakeholders in decision making about regulation of GM crops and the relative roles of science, ethics and values in policy and regulatory processes.

The Cartagena Protocol on Biosafety of the Biodiversity Convention, agreed in January 2000 when environment ministers and trade negotiators from 138 governments concluded five years of talks, was the first binding international agreement addressing situations where GMOs are traded across national borders (Cosbey and Burgiel, 2000). Under the Protocol governments will signal whether they are willing to accept imports of agricultural commodities that include living modified organisms (LMOs)[4] and shipments that may contain LMOs are to be clearly labelled. For seeds, fish and other LMOs that are to be intentionally introduced into the environment, the exporter must provide detailed information to each importing country in advance of the first shipment, and the importer must then authorise the shipment. The aim is to ensure that recipient countries have both the opportunity and the capacity to assess risks presented by GMOs.

A major international conference was held under the auspices of OECD to consider food-related problems associated with the marketing and consumption of GM crops and foods

[4] The distinction between all GMOs, including products derived from them, and LMOs, was an important point of debate in the negotiations. LMOs are presumed capable of replication and would include seeds (e.g. maize or soya) for planting as agricultural crops or for animal feed. Ground maize or soya including material from GMOs would not be classed as an LMO.

(OECD, 2000). The main recommendation to emerge was that an independent panel of experts of international standing should be convened, on similar principles to the Intergovernmental Panel on Climate Change, to contribute on an impartial basis to decision making on GM crops.

10.1.2 The Precautionary Principle

The adoption of the PP as a basis for risk regulation in the EU has given rise to concerns from various points of view. In WTO negotiations, the PP has been attacked particularly by US negotiators on the grounds that, since it is not based on sound science, it is being used to restrict trade, for example in hormone treated beef and GM crops and foods. In defence of its position and in response to concerns about variable interpretation of the PP, the EC has established guidelines for its use (Commission of the European Communities (CEC), 2000).

Recourse to the PP is taken to imply that potentially dangerous effects from a product or process have been identified and that scientific evaluation does not allow the risk to be determined with sufficient certainty. The EC paper claims that the Community has the right to establish the level of protection, for example for the environment, that it deems appropriate and measures based on the PP are expected to be:

- proportional to the chosen level of protection;
- non-discriminatory in their application;
- consistent with similar measures already taken;
- based on an examination of the potential benefits and costs of action or lack of action;
- subject to review in the light of new scientific data; and
- capable of assigning responsibility for producing the scientific evidence necessary for a more comprehensive risk assessment.

This clarification of the Commission's interpretation of the PP will be very helpful to regulators but seems unlikely to meet the expectations of environmental pressure groups (Greenpeace, 2000). Also the clear reservation of the rights of the EU to set more stringent standards for its territory than other countries has yet to be tested under WTO rules.

10.1.3 National developments

In most European countries the regulatory and policy environment for the development and marketing of GM crops has been changing in response to public concerns, pressure from environmental and consumer groups, developments in scientific understanding and evolution of industry strategies.

For example, the UK has established more formal regulatory procedures than before, clarifying the precautionary approach for GM crops and food, negotiating a voluntary moratorium with industry until farm scale field trials are completed, and setting more stringent regulatory standards based on field scale trials and evaluations. The trials will test particularly whether GM crops will result in more intensive use of broad-spectrum herbicides and whether this could damage biodiversity. The UK government has also been under pressure to adopt more stringent standards for the environmental impacts of GM crops or even to steer farmers' choices away from GM crops as a contribution to more sustainable farming systems. As a result it has established the Agriculture and Environment Biotechnology Commission (AEBC) to advise on the general direction for the role of GMOs in agriculture, defining which impacts will be acceptable and identifying the potential for biotechnology to contribute to sustainable agricultural practices (DETR, 1999).

10.2 Policy impacts and outcomes: employment, international competitiveness and environment

As indicated in the previous sections the policy environment has had a range of impacts on industry strategies and, by implication on the overall outcomes of interest – employment, international competitiveness and environmental improvement.

10.2.1 Policy impacts

The following are the main points to emerge from the interviews with companies and PSREs.

1. Public policy influences on companies are subtle and in many cases have an indirect rather than a direct influence on product development strategies. Major direct influences of policies on product development decisions are uncommon. Obviously directives and regulations are obeyed and lived with, but they are not the main drivers in company foresighting and strategic thinking.
2. Policy initiatives promoting innovation have become more common, expressing the desire of national governments and the EU to speed the progress of new ideas from the laboratory to the market place and hence to maintain competitiveness in a global trading environment. However, government policies such as Foresight in the UK have had little direct impact on innovation in agro-biotechnology companies which have always been highly innovative and well accustomed to working to extremely long development time scales.
3. There is little doubt at government level about the need for, and benefits from, public support for fundamental research and for training highly qualified scientists, engineers and managers.
4. Policies to support innovation, particularly in the agro-biotechnology area, *could* lead to faster development of a range of technology options with the potential to improve the sustainability of farming systems by reducing the use of pesticides and improving the quality or yield of the crop but evidence so far for this outcome is still contested.
5. Public investment in new or existing small companies beyond the fundamental research stage is unlikely to lead to corresponding public benefits. Earlier research has shown that the most likely fate of successful agro-biotechnology SMEs is to be taken over by an MNC. The barrier to entry for small firms in this industry arises from the strong regulatory regimes – only large companies can tolerate the long lead times and build up the expertise needed to deal with regulatory systems world-wide. Thus, given that regulatory regimes are in general becoming stricter and more complex, the direction of innovation in pesticides and biotechnology and its contribution to sustainable farming is likely to be dictated by MNC strategies.
6. SMEs in this sector do, however, provide a significant source of employment and an effective route for the translation of new ideas from concept to market realisation. One emerging trend is the increasing use by MNCs of specialist research units (private and public), for example for specialist research on combinatorial chemistry and for development of robotic systems for high-throughput screening of pesticides.
7. Companies do take account of public opinion and attitudes and they find the public resistance to GM products a source of extreme uncertainty. They also find it difficult to relate to pressure groups, NGOs and broad environmental coalitions. They feel they must take account of these factors but have not so far found a coherent way of doing so.
8. The smaller seed companies are more vulnerable to unpredictable constraints, regulations and market fluctuations than MNCs.
9. Companies see some policy signals as clearer and easier to take on board than others, particularly those such as CAP developments and trade liberalisation signals that operate through market mechanisms, markets being one of the main foci for technology forecasting. Environmental signals and precautionary regulation are seen by some

companies as hard to manage although few are arguing against them. Most MNCs are close to policy making and regulatory circles and while they may criticise some decisions and regulatory trends, they incorporate new policy processes and adjust to them on a day-to-day basis. During the product screening process, decisions are based on regulations and directives and, other things being equal, potential products which are environmentally more sensitive will be given greater priority than less sustainable products.

10. All big and most medium sized companies publicise their support for sustainable development and integrated crop management initiatives, for example Bayer's Responsible Care Initiative, and Novartis' commitment to ICM incorporating crop rotation techniques. However, at the strategic level environmental policies do not seem so prominent in decision making on new product development and in most cases, the concept of sustainable agriculture is less stringently applied by MNCs than would be, for example, in a PSRE.
11. The major factors in industry product development decision-making are market opportunities and technological innovation. New opportunities for combined agrochemical and biotechnology trajectories are leading to stronger pressures to link agrochemicals and biotechnology/seeds competencies within MNCs although all companies are in various stages of articulating this synergy between chemistry and biology.
12. MNCs involved in this project face the need to invest in biotechnology R&D and to continue to invest in agrochemicals R&D at a time when the world market for pesticides (the main source of funds for investment) is relatively static or declining. These factors are leading to a spate of mergers to achieve global economies of scale and to some companies splitting off their agrochemical from their pharmaceutical divisions.
13. Plant biotechnology is taking an increasing, but as yet minor, share of innovation resources. Some companies are building new alliances and research consortia to investigate second and third generation 'output' traits in nutraceuticals and functional foods.
14. PSREs are being expected to serve both public and private roles in these areas: contributing, as publicly funded bodies, to the development of new ideas; working with industry to facilitate their exploitation in the market place; and also working, again in a public role, with governments in support of regulatory systems, particularly for GM crops. The tensions between these various roles are placing strains on the traditional independence and impartiality of PSREs and there is a need to reinforce their independent role in risk assessment.

10.2.2 Employment and competitiveness

The employment study (Annex F1 and Section 9 of this report) indicated that innovation in the agrochemical, biotechnology and seeds sectors is likely to create some direct job opportunities in the EU and also major indirect opportunities throughout the agro-food chain. New quality traits introduced into GM crops are expected to have the biggest positive impact on indirect employment. On the other hand, competition effects among companies are likely to reduce the numbers employed in the sector as a whole. Extrapolating to the global level, it seems unlikely that innovation in agro-biotechnology and seeds will generate significant new direct employment opportunities, although those that are created are likely to be for well-qualified staff.

In addition to the indirect employment opportunities down-stream in the agro-food chain, it was clear that the increasing trend of MNCs to outsource significant components of their up-stream R&D activity, for example in genomics, combinatorial chemistry and the development of high throughput screening equipment, is creating employment opportunities among SMEs not directly involved in the agro-biotechnology trajectory.

The results of these interactions are difficult to predict. In addition, several of the managers interviewed commented on the potential of the technology to spring surprises, positive and negative. These factors will also be affected by the continuing uncertainties surrounding European and global acceptance of GM crops and the influence this has on agro-biotechnology trajectories.

As noted earlier, strategic decision making on the scale and location of R&D activities in these industry sectors is mainly on a global scale. Decisions taken on the basis of company competitiveness can thus have long term impacts on employment and also competitiveness at national and European levels. Many of the factors influencing these decisions will thus have their origins beyond the EU. Nevertheless, European policy decisions are not totally without impact on the companies studied in this project. Some managers commented that, if no GM products are being marketed in Europe, it would be more efficient for the company to locate its headquarters close to its main markets. This presumably would mean that European companies would locate their headquarters in the USA and would through time cease to be 'European' in the sense noted in Section 5.

Company predictions that they would be forced by EU regulatory inconvenience to move their headquarters to the USA have been made for some time and have not yet been borne out. However, there has been a long term process of attrition. Many of the European MNCs have moved the location of their biotechnology discovery strategies to the USA, although mainly for reasons associated with knowledge generation rather than regulation. R&D headquarters for pesticides are generally still located in Europe but as the agro-biotechnology trajectory gets under way, with its potentially stronger links between chemicals and biotechnology strategies, and as it is progressed further down the development pipeline, there is a possibility that Europe will be sidelined. One factor which would at least delay this outcome is the spread of public opposition to GM crops to other major cropping regions of the world with corresponding delays in the evolution of the global agro-biotechnology trajectory.

10.2.3 Environmental quality and biodiversity

The European regulatory environment, considering economic and other policy instruments, has been evolving for some time along a direction that encourages the minimisation of pesticide use and the parallel development of new pesticides that have a continuing improvement in their environmental impact. However, there is as yet no serious integration at the policy level to match the increasing sophistication of integration of the agro-biotechnology trajectory in industry planning strategies.

Considering policies directed to farmers in order to reduce the level of pesticide use, the marginal impacts seen so far are due to a range of interacting influences, only some of which are policy related. The widely used policy argument that reducing the level of state subsidies to farmers will reduce their use of potentially damaging chemicals may not be valid. Research in New Zealand suggests that, although subsidy removal may improve environmental health in the short term, in the long term it may decline (Bradshaw & Smit, 1997). Such policies are also unlikely to stimulate the uptake of new, potentially cleaner technology which, at least initially, will be more expensive than many competing products.

GM crops have a greater potential than pesticide regulations and policies to reduce levels of pesticide use although opinions differ about the relative risks and benefits. For example, insect and disease resistant crops, developed either through GM or through conventional breeding technologies, would reduce, but not eliminate, the need for pesticide applications. Herbicide resistant crops also have the potential, if treated appropriately by farmers, to improve the environmental performance of some cropping systems (Dewar *et al.*, 2000).

An additional environmental benefit, not necessarily in Europe, is that if fewer pesticides are applied the number of chemical factories (with attendant point source pollution problems and health risks to workers) can be reduced and there will be less wastage of fossil fuels in the transport and application of chemicals.

The pesticide regulatory regime has been evolving since the 1960s in a reactive/preventive manner, incrementally eliminating from the lists of approved products any that are shown to cause damage to the environment or human health (Tait and Levidow, 1992). As demonstrated by the nature of new products being developed by the companies we interviewed, regulatory evolution is having an impact and new pesticides are more benign, for the environment and for the health of agricultural workers, than previous generations of product.

Pesticide taxes are increasingly part of the policy agenda at EU and national levels. They may be applied indiscriminately to all pesticides or selectively to pesticides regarded as most damaging to health or the environment. In the latter case they may act as an incentive to industry to develop new chemicals that would avoid the tax, i.e. as a means to create the necessary incentive to knock older and more damaging products off the market. Although taxes have had support from some policy makers and environmental groups, they were generally seen by industry and agricultural economists we interviewed as largely ineffective.

Regulatory review can stimulate innovation by removing products regarded as undesirable from the market and creating market niches for new, more environmentally sustainable products. This was seen by industry managers as a more effective method than taxes to encourage change, for example by creating markets for the newer, more benign but more expensive pesticides now in development.

In European policy circles, there appears to be a consensus emerging that GM crops have been introduced with undue haste and perhaps with insufficient attention to the need for public reassurance based on widely available evidence of safety and also public choice based on clear labelling.

The cost of GM seed production is particularly inhibiting for independent seed companies which do not have the resource base of the agro-biotechnology MNCs and companies with most sales in Europe are most affected by European uncertainties (e.g. Limagrain, KWS, Danisco, and to a lesser extent, Advanta). The more conservative firms with little or no biotechnology investment may find marketing conditions easier in the short term and these are also the firms that have been stimulated by increasingly stringent pesticide regulation to concentrate on the development of pest and disease resistance characteristics in new seed varieties, leading to further savings in pesticide use. If GM crops start to expand market share in Europe, however, these firms and also the remaining independent seed companies which are developing GM crops will find themselves increasingly vulnerable to the agro-biotechnology trajectories of the major MNCs.

Pesticide saving and environmental improvement was also an important component of the second generation agro-biotechnology trajectories outlined in Section 5 above. However, one strand of these trajectories conceived the development of higher value niche market products as justifying higher levels of crop protection, whether by GM or chemical means, and hence generating improved profits.

10.3 Integrated policy developments for Europe

The PITA project has had two major foci – analysis of strategic decision making in companies developing pesticides, GM crops and seeds, and in PSREs; and an integrated policy analysis of the environment within which these companies are operating and the impact of that environment on their decisions. Recent political developments in Europe and the USA have been accompanied by more insistent calls for integrated approaches to policy analysis (Giddens, 2000) accompanied by greater openness to stakeholder participation in decision making.

These demands for more integrated approaches are driven by the realisation that policies often deliver much less than is expected or intended, because of counter-productive interactions among the key actors, or because the policies arising from different sectors of the policy environment conflict with one another. On the other hand, where interactions among the actors or the policies are mutually supportive, the desired outputs can be achieved more rapidly and at less public cost.

The comprehensive interdisciplinary policy analysis and the methods adopted for the study of company and PSRE strategies in this project have enabled us to identify some of these potential synergies and antagonistic effects for this important industry sector and to suggest points of leverage for policy intervention. The insights gained from industry managers and policy makers about the reality of their interactions with one another and with the policy process have set the scene for further integrated policy developments in other areas, including science, technology and innovation more generally, transport and environment, rural development and risk analysis (see WWW.ed.ac.uk/rcss/supra/policy development). Policy makers and those who react to policies usually have expertise only in a narrow area of the overall policy spectrum and mechanisms are needed to enable them to envisage and respond constructively to wider policy interactions and the scope for policy synergies and antagonisms.

11. Dissemination

Dissemination of the PITA project has been conducted via website, publications, conference presentations workshops, and the development of journal Special Issues.

In order to disseminate the results of PITA as quickly and widely as possible, a PITA website was constructed in the early stages of the research:

http://technology.open.ac.uk/cts/projects.htm#biotechnology

This can be accessed via a two-way hotlink with the DGXII TSER web pages.

A full list of publication and conference presentations (a total of 16 refereed articles published, and twelve other publications or presentations) is detailed in Annex G1. Articles have, so far, been accepted in Nature Biotechnology, Technology Analysis and Strategic Management, Agbioforum, Economies et Societes, and Science and Public Policy, among other journals.

Partners have also set up workshops focused on relationships with user groups. IDR, Spain, for example, organised a meeting in Malaga, with Andalusian regional government representatives, biotechnology researchers, farmers, consumers and companies, to discuss impacts of biotechnology on Andalusian agriculture. The French partners (INRA and QAP) organized a satellite meeting 'Socio-economic challenges of plant biotechnology development in Europe' associated with the International Conference New Frontiers in Plant Science and Plant Biotechnology, in Toulouse March 2000, with speakers from PITA partners.

Joyce Tait was the organiser of the Society for Risk Analysis Annual Conference, Edinburgh, entitled Foresight and Precaution, where PITA related research was presented.

We plan an intensive publications programme over the next twelve months, with the possibility of special issues of journals, and of dissemination workshops.

12. References

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13. Annexes

Annex A Partners

A1 Partners: full list with researchers

Annexes B Objective 1 Reports

B1 An Integrated Analysis of Government Policies Influencing Innovation in the Agro-chemical, Biotechnology and Seed industries – Jos Bijman, October 2000

B2 Conclusions on National Policy Environment for Seeds, Agrochemical and Biotechnology in Denmark, France, the Netherlands, Spain and the UK – Jos Bijman, December 1998 (already submitted)

B3 European Union Policies on Agrochemicals, Biotechnology and Seeds – Jos Bijman and Joyce Tait, Eds., with partners, December 1998 (already submitted)

B4 Denmark National Policy Report – Villy Sogaard and Jesper Toft, December 1998 (already submitted)

B5 France National Policy Report – Isabelle Jorge, Pierre-Benoit Joly, Stephane Lemarie and Gerald Assouline, December 1998 (already submitted)

B6 Netherlands National Policy Report – Jos Bijman, Floor Brouwer, Freek de Meere and Sieman van Berkum, December 1998 (already submitted)

B7 Spain National Policy Report – Jose Carlos Cuerda, Alejandro Garcia, Ana Goitia and Esther Gravalos, December 1998 (already submitted

B8 United Kingdom National Policy Report – Nick Barnes, Susan Carr, Joanna Chataway, Les Levidow, Dave Wield and Joyce Tait, December 1998 (already submitted)

B9 German National Policy – Matthias Hocke, December 2000

B10 European Public Attitudes to New Agricultural Technologies: an overview – Nicholas J. Barnes, December 1999 (already submitted)

B11 Euro-Food: Pressures on R&D – Les Levidow, November, 2000

Annexes C Objective 2 Reports – Multinational Company (MNC) Monographs and Overview

C1 Interactions between Public Policies and Company Innovation Strategies: Overview of the company monographs – Gerald Assouline, Pierre-Benoit Joly and Stephane Lemarie, January 2001

C2 Cognitive Maps of Company Monographs – Sue Oresczcyn, with PITA partners, January 2001

C3 Advanta Monograph – Jos Bijman and Marc-Jeroen Bogaardt, December 2000

C4 AgrEvo Monograph – Jos Bijman and Marc-Jeroen Bogaardt, October 2000

C5 BASF Monograph – David Wield, October 2000

C6 Bayer AG Monograph – Villy Sogaard, December 2000

C7 Royal Cebeco Group Cooperative Monograph – Jos Bijman and Marc-Jeroen Bogaardt, October 2000

C8 Danisco Monograph – Villy Sogaard, December 2000

C9 KWS SAAT AG Monograph – Jos Bijman and Marc-Jeroen Bogaardt, September 2000

C10 Limagrain Group Monograph – Pierre-Benoit Joly and Isabelle Jorge, November 2000

C11 Monsanto Monograph – Joanna Chataway and Joyce Tait, October 2000

C12 Novartis Agribusiness Monograph – Joyce Tait and Joanna Chataway, December 2000

C13 Pioneer High-Bred International Monograph – Stephane Lemarie, November 2000

C14 Rhone Poulenc Agro Monograph – Gerald Assouline, September 2000

C15 Seminis Vegetable Seeds Monograph – Esther Gravalos Alejandro Garcia and Jose Carlos Cuerda, November 2000

C16 Zeneca Agrochemicals Monograph, Joyce Tait and Joanna Chataway, November 2000

Annexes D Objective 2 Reports on Small and Medium Enterprises (SMEs) in agrochemicals, seeds and plant biotechnology

D1 Small and Medium Enterprises (SMEs) in Agrochemicals, Seeds and Plant Biotechnology: Overview – Esther Gravalos and Alejandro Garcia, October 2000

D2 SMEs in the Danish Agrochemicals, Seeds and Plant Biotechnology Industries – Villy Sogaard, November 2000

D3 SMEs in the French Seeds, Biopesticide and Plant Biotechnology Industries – Stephane Lemarie, Pierre-Benoit Joly and Isabelle Jorge, January 2001

D4 SMEs in the German Seeds and Plant Biotechnology Industries – Matthias Hocke, December 2000

D5 SMEs in the Netherlands Agrochemicals, Seeds and Plant Biotechnology Industries – Jos Bijman and Marc-Jeroen Bogaardt, September 2000

D6 SMEs in the Spanish Agrochemicals, Seeds and Plant Biotechnology Industries – Esther Gravalos and Alejandro Garcia, October 2000

D7 SMEs in the United Kingdom Agrochemicals, Seeds and Plant Biotechnology Industries – Nicholas J Barnes, October 2000

Annexes E Objective 2 Reports on Public Sector Research Establishments (PSREs) in the Fields of Agrochemicals, Seeds and Plant Biotechnology

E1 Public Sector Research Establishments (PSREs) in Agrochemicals Seeds and Plant Biotechnology: Overview – Villy Sogaard, January 2001

E2 Danish PSREs in the fields of Agrochemicals, Seeds and Plant Biotechnology – Villy Sogaard, December 2000

E3 French PSREs in the Fields of Agrochemicals, Seeds and Plant Biotechnology – Pierre-Benoit Joly, July 2000

E4 German PSREs in Agrochemicals, Seeds and Plant Biotechnology – Matthias Hocke, December 2000

E5 Netherlands PSREs in Agrochemicals, Seeds and Plant Biotechnology – Jos Bijman and Marc-Jeroen Bogaardt, September 2000

E6 Spanish PSREs in Agrochemicals, Seeds and Plant Biotechnology – Esther Gravalos and Alejandro Garcia, October 2000

E7 United Kingdom PSREs in Agrochemicals, Seeds and Plant Biotechnology – Susan Carr and Sue Oreszczyn, October 2000

Annexes F Objective 3 – Report on Employment

F1 Effects of Innovation in the European Agrochemical and Seeds Sectors on Employment and Competitiveness: Objective 3 Report, Anthony Arundel, December 2000

Annex G Publications

G1 PITA project publications and other outputs