The making of biotechnology: a case study of radical innovation

Thesis

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THE MAKING OF BIOTECHNOLOGY: A CASE STUDY OF RADICAL INNOVATION.

BY

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ABSTRACT

This study examines decision making in large and small firms undertaking biotechnology innovation and identifies factors influencing innovation. It also considers aspects of environments external to firms, but relevant to the process of innovation. The study suggests that innovation is best understood as process of change both within the firm and in the external environment.

Factors internal to firms influencing key decisions included economic and political evaluations, company culture, organization, and in large firms, previous areas of corporate activity. A scarcity of appropriate knowledge relating to technical and non-technical aspects of innovation acted as severe restraints to Dedicated Biotechnology Firms (DBFs). Factors external to firms shaping decisions about the technology included changes in the socio-economic and political environment, risk regulation and patenting. Lack of funding and difficulties associated with venture capital constituted additional hurdles for DBFs.

The findings of the study highlight a series of erroneous assumptions built into the linear model of innovation. The cumulative nature of innovation and the importance of 'learning by doing' constitute elements of the critique of the linear model. For related reasons, some Post Fordist theories of current change in advanced industrialized countries, particularly those which advocate flexible specialization as a new model for industrial growth also prove problematic.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF SYSTEMS DIAGRAMS

LIST OF COPE MAPS

CHAPTER 1. THE MAKING OF BIOTECHNOLOGY: A CASE STUDY OF RADICAL INNOVATION.

This thesis examines aspects of biotechnology innovation during the nineteen eighties and early nineteen nineties. Two general questions guided the study: What are the primary factors influencing biotechnology innovation in agricultural and food sectors? How does the study of biotechnology innovation inform theories of technical change?

These questions translate into three more defined thesis objectives: 1) To identify the principal factors influencing decision making about biotechnology innovation in Dedicated Biotechnology Firms (DBFs) and large Multinational Corporations (MNCs) interested in developing biotechnology products and processes; 2) To examine how market and non-market forces are influencing the rate and direction of food and agriculture - related biotechnology innovation. 3) To consider the implications of research findings for theories of innovation.

The study is based on extensive, semi-structured interviews with managers in large and small firms involved in biotechnology innovation. This introductory chapter outlines the issues with which the thesis is concerned.

Chapter 2 discusses methodology. Chapter 3 describes and analyses factors influencing the rate and direction of innovation in DBFs and Chapter 4 does the same for MNCs included in the study. Chapter 5 examines institutions and markets emerging in conjunction with biotechnology and examines their interaction in the innovation process. Chapter 6 analyses debates about risk regulation and patenting of the technology and contending views about the impact which existing regulatory regimes have on innovation. Chapter 7 summarizes the findings and considers the theoretical implications.

1.1. BIOTECHNOLOGY: AN OVERVIEW.

Biotechnology has been defined in a number of different ways. Some definitions include all products of biology used for human ends and others restrict the focus only to products of genetic engineering. I will define the set of techniques in the following way: The body of,

> "knowledge and techniques involving the integrated use of biochemistry, microbiology, genetics and engineering sciences to achieve the technological application of capabilities of micro-organisms, cultured tissue cells and parts thereof" (Orsenigo,1989:32).

This definition incorporates a range of knowledge and techniques rather than just genetic engineering. This is important. Many of the managers interviewed in this survey stressed that current techniques represented a 'knowledge revolution', based on a new understanding of biological sciences and opened up a host of previously unimagined possibilities. In this sense, new biotechnology is conceived as emerging from new procedures and rules for the biological sciences. However, while genetics played a central role in creating a new scientific paradigm, genetic engineering was not always an integral part of the work. Thus, this definition proves more congruent with the

perceptions of those incorporating the knowledge and using the new techniques than either very broad or very narrow definitions. Additionally, it focuses attention on the multi and interdisciplinary nature of the technology and its "strong scientific foundation" (Orsenigo:1989:32). The definition encompasses industrial activities based on fermentation, cell culture and biocatalytic processes, and includes biomedicine and agriculture in so far as they involve the application of cellular or molecular biology (Oakey et al,1990:5-6).

Clearly, biotechnology spans a number of sectors. Indeed, the term 'biotechnology' industry is somewhat of a misnomer. Table 1 gives some idea of major applications of biotechnology in different sectors, apart from agriculture. Table 2 gives a more detailed account of agricultural inputs and provides estimated timelines (estimates made in late eighties) for development and the predicted effect on agricultural productivity. (Appendix 1 contains explanation of some relevant scientific terms and components of biotechnology.)

The tables are by no means exhaustive and the difficulty of summarizing applications is further complicated by indications that biotechnology will encourage the development of new sectors. For instance, 'pharmetics', the combination of various elements of both the pharmaceutical and cosmetic industries and new areas of healthcare that bring the pharmaceutical and food sectors much closer together. The use of animals in the healthcare sector, for instance the use of sheep to produce blood clotting agents and pigs to 'grow' human organs for transplants, blur the boundaries between agriculture and healthcare.

Table 1.1. BIOTECHNOLOGY ACCORDING TO INDUSTRIAL SECTOR.

Sector	Activities
Chemicals (bulk)	Ethanol, Acetone, Butanol Organic Acids
Organic (fine)	Enzymes, Perfumeries Polymers (mainly polysaccharides)
Inorganic	Metal benefaction, bioaccumulation and leaching (Cu, U)
Pharmaceuticals	Antibiotics Diagnostic agents (Enzymes antibodies) Enzyme inhibitors Steroids Vaccines
Energy	Ethanol (gasohol) Methane (biogas) Biomass
Food	Dairy, fish and meat products Beverages (alcoholic, tea Coffee) Baker's yeast Food additives Novel foods Mushroom production Amino Acids, vitamins Starch products Glucose and high fructose syrups, Functional modifications of proteins, pectins, Toxin removal, Rapid detection of microbial contamination
Service Industries	Water purification Effluent treatment Waste management Oil recovery Analytical tools.

Adapted from (Orsenigo 1989:37-38)

Table 1.2. IMPACTS OF BIOTECHNOLOGY ON AGRICULTURAL PRODUCTIVITY.

Development	Likely Time scale of Implementation	Effect on Agricultural Productivity
Plant Breeding and Crop development		
Micropropagation	Already in commercial use	To speed up implementation of other developments
Nitrogen Fixation		
-with non-leguminous plant tissues	Long term	Input saving
-by free living soil bacteria	2000*	Input saving
-improving efficiency of nitrogen fixation within legumes	1995*	Input saving
-improving fertilizer uptake by cereal plants	1995*	Input saving
Harnessing microbial plant interactions		
-frost protection	Undergoing trials	Loss Avoidance
-growth promotion	Under development	Increased productivity
Extensions of classical plant breeding		
-insect and disease resistance in plants	Under development	Loss avoidance and input saving
-improved stress resistance	1995*	Increased productivity

-better storage	Under development	Loss avoidance
New developments in crop protection		
-biological control agents	1995*	Input saving
-herbicide resistance	Under development	Improved efficiency
Animal Breeding and Health		
Improved disease control	Already available	Increased productivity
Embryo transfer		
-predetermined sex ratios among offspring	Already available	Improved efficiency
-increased reproductive capacity of pedigree females	Already available	Increased productivity
Improved feed conversion, e.g. using natural growth hormones	Under development	Increased productivity
Developments in animal feeds	1995	Use of crop wastes or non-crop products
Industrial Developments		
Enzyme technology		
-high fructose corn syrup	Already in use	Substitutionist
-rennet production	Already in use	Substitutionist

Microbial food production processes using non-agricultural substrates, e.g. single cell protein	Already in use	Substitutionist
Energy cropping	Already feasible (timing of implementation dependent on oil prices)	Land use diversification
New sources of chemical industry feedstock		
-from plants	Already in use on small scale	Land use diversification
-from animals	Successful at research stage	Land use diversification

(Tait et al,1990, adapted from J.J. North,1986:3-14)

Some excellent explanations and histories of biotechnology exist, (Faulkner, 1986, Yoxen,1986). Table 1.3 summarizes the historical evolution of the technology, categorizing it into three generations.

Table 1.3. THE HISTORICAL EVOLUTION OF BIOTECHNOLOGY.

FIRST-GENERATION BIOTECHNOLOGY (c.7000 BC)

-Empirical practice, characterized by minimal scientific and engineering inputs.

-Includes the traditional use of fermentation to produce food, drinks and energy.

SECOND-GENERATION BIOTECHNOLOGY (1940s)

- Characterized by the organization of scientific and engineering inputs to industrial-scale processes.

-Based on the integrated application of industrial microbiology (using mutation and screening procedures), biotechnology and chemical engineering

-Includes the use of fermentation, bioconversions and biocatalysis to produce pharmaceuticals, chemicals, fuels and food, and to process waste

-Recent technical developments - immobilization and plant-tissue culture techniques

THIRD GENERATION BIOTECHNOLOGY. (1970s)

-Characterized by the production of 'novel genetic combinations'

-Based on the application of molecular biology and the use of genetic engineering (recombinant DNA and hybridoma techniques)

-Potential applications include all existing biological processes, as well as numerous novel products and processes.

(Faulkner, 1986)

While the development of third generation techniques dates to the 1970s, the scientific roots of the new era can be traced much further back and the knowledge that characterizes each generation is cumulative. Gregor Mendel died in 1884 with no idea of the primary importance that his work would have on plant and animal breeding or genetics in general. Mendel's work in identifying 'heredity factors' present in both parents of the pea varieties which he was working with showed that hereditary traits from parents do not blend in offspring, but rather, separate (Hobbelink,1991:20).

The first half of the century saw many improvements in the use of microbes for industrial production, which benefited enormously from Pasteur's discovery that fermentation involves living cells. This work laid the basis for 2nd generation technology. Post war development of fermentation processes for the production of antibiotics gave an impetus for continued progress and the 1940s and 1950s saw continued advances in fermentation technology that inspired the development and refinement of other

biotechnological procedures, including bioconversion processes, and biocatalysis (Oakey et al,1990:9). The 1940s also witnessed a major scientific breakthrough that built on Mendel's work and was the foundation of 3rd generation techniques. Oswald Avery, a Canadian doctor established that the hereditary factors, identified by Mendel, are located on the DNA (deoxyribonucleic acid). He and his colleagues began to transfer DNA from one micro-organism to another, thus proving that hereditary information is stored on it (Hobbelink, 1991:20).

Watson and Crick 'discovered' the double helix structure of DNA in 1953. This laid the basis for future research in important ways. Their findings account for the integration of biochemistry and genetics in the form of molecular biology and thus in some sense paved the way for the 1973 gene splicing experiments that represented the first successful use of recombinant DNA techniques (Oakey et al,1990:12-13). The other scientific 'event' that is closely associated with 3rd generation techniques took place in 1975 when Kohler and Milstein first produced Monoclonal Antibodies. While it is always misleading to suggest that isolated events can tell the whole story about the progression of a science or technology, the events described above do constitute landmarks in the life of what is both a very ancient and very modern set of techniques.

The cluster of techniques that constitute 'new biotechnology' (including genetic engineering, bioprocessing, monoclonal antibodies, protein engineering, bioinformatics, tissue culture, biological sensors, protoplast fusion, immobilized enzyme and cell catalysis, biocatalytic reactors, computer linkage of reactors and processes) has attracted speculation about their potential to revolutionize whole sectors of industry, and to transform the way goods and services are produced.

The Spinks report, published in 1980, provided recognition of this possibility in the UK:

> "Over the next two decades, biotechnology will affect a wide range of activities such as food and animal feed production, provision of chemical feedstocks, alternative energy sources, waste recycling, pollution control and medical and veterinary care" (ACARD,1980:160).

Additionally, in the longer term, Spinks saw a much broader and profound shift taking place,

> "Genetic manipulation...has become a practical and quite general proposition...This advance in our view confers on biotechnology an importance comparable to that of atomic physics, electronics, and most recently, microelectronics. It has been said, that 'biology will launch an industry as characteristic of the twenty-first century as those based on physics and chemistry have been of the twentieth century" (ACARD,1980:160).

The report reflected a widely held belief that biotechnology would make short term and longer term contributions to industry and society. To be sure, an enormous amount of hype was generated much of it in an effort to whip up funds with which to exploit new opportunities (Tait et al,1990). Despite this, the technology did promise to be a revolutionary force, changing both industrial, agro-industrial and agricultural process and offering a whole new range of products and sectors (Yoxen,1986). There were a number of important contextual factors that contributed to the loudly voiced expectations that biotechnology would quickly become a pervasive technology.

1.2. THE HISTORICAL CONTEXT.

Much of the optimism surrounding biotechnology within both business and academic communities had to do with

timing and context. Second and third generation techniques have been largely developed in technologically advanced capitalist societies and have been shaped by a complex web of interacting factors. In trying to understand any particular technology it is of vital importance to consider not only the techniques but also the social institutions with which they interact. As Noble points out,

> "...technology does not necessitate. It merely consists of an evolving range of possibilities from which people choose. A social theory of technology that explores beneath the appearance of necessity to illuminate these possibilities which technology embodies, reveals as well the contours of the society that realizes or denies them" (Noble,1984:xiii, Quoted in Kloppenburg,1988:8).

The focus of this thesis is on the firm and the manager as units of analysis. The approach taken here is constructed to shed light on how managers interpret their environments, internal and external to the company, considerations that influence their decisions and therefore, in turn, the rate and direction of innovation (chapter 2 discusses the relationships between manager, firm and external environment and considers methodological issues). The firm, however , cannot be considered in isolation; in order to understand the boundaries within which firms and managers work, and the perceived opportunities which biotechnology represented, some consideration of context is important. Thus, chapters 5 and 6 examine aspects of the broader environment of biotechnology innovation. Additionally, although of course incomplete, this section identifies some of the particular elements of 'context' which contributed to the speculation that biotechnology would have a major impact on the global economy.

1.2.1. THE PATTERN OF INNOVATION IN AGRICULTURE.

First, one of the primary reasons that biotechnology was perceived as a 'useful' set of techniques is that it would fit into and extend technological trajectories established in the agricultural and food sectors. Goodman et al (1987) predicted that biotechnology would contribute to long-standing dynamics governing capitalist agriculture. According to this theory, there are two main ways in which capital, unable to use mechanisms of control developed in industry,[1] deals with the peculiar and unpredictable constraints of agricultural production. 1) Substitutionism, which involves the substitution of industrially produced goods for agriculture, thereby by-passing the peculiar and unpredictable aspects of nature, inherent in agricultural production. Examples of this include, synthetic fibres for cotton, synthetic dyes for indigo. 2) Appropriationism, which involves the attempt by industrial capitals to take over discrete elements of the agricultural process, transform them into industrial activity and re-incorporate them into agriculture as purchased inputs, for example synthetic fertilizers.

Kloppenburg, in his major study of the political economy of plant breeding, also sees the pattern of biotechnology innovation fitting into historical models. Capitalist agriculture uses both technical and social means

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[1] A long-standing debate exists over the extent to which capital has been able to penetrate agriculture. While Marxist schools of thought have focused on the question of social relations and neo-classical economists on factor endowments, Goodman et al look at the problem from a different angle. They say, "..agriculture confronts capitalism with a *natural production process*...agriculture could not be directly transformed into a branch of industrial production. There was no industrial alternative to the biological transformation of solar energy into food. The industrialization of agriculture therefore took a decisively different path." (Goodman et al,1987:1)

to achieve the 'commodification'[2] of agricultural inputs and biotechnology would contribute further to the logic of accumulation established in agriculture.

> "The emerging social impacts of the new genetic technologies in the plant sector, are substantially, logical extensions of historically established processes. The logic is that of the capitalist mode of production: the concentration and centralization of capital in the seed industry, the commodification of the seed, the decline of the petty commodity producer, the struggle over the state apparatus, and the continued appropriation of the plant genetic resources of the Third World" (Kloppenburg,1988:277).

History suggested that biotechnology, offering new techniques to make nature succumb to the control of capital, would be adopted as an extremely useful new tool by companies with interests in agricultural production. However, technological trajectories in agriculture and food have been established within a social framework of regulations, patents, and plant breeders' rights. Biotechnology innovators, regulatory bodies and pressure groups clashed over the sort of framework within which innovation could and would take place. Moreover, biotechnology proved an emotive subject amongst pressure groups concerned both about control of agricultural production and with green issues. The struggle about how innovation should be controlled and who should control it has influenced both the rate and direction of innovation. These issues will be further discussed in chapter 6, which considers the impact of social and political factors, such as risk regulation and patents.

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[2] Commodification is a key Marxist concept. The commodity is the form products take when they are exchanged in capitalist systems. (Marx:1976) Kloppenburg writes, "The fundamental historical processes associated with the political economy of capitalism are...those of *primitive accumulation*, the separation of the worker from the means of production, and *commodification*, the extension of the commodity form to new spheres." (Kloppenburg,1988:9)

1.2.2. COMMODITY CHEMICALS AND THE ADOPTION OF BIOTECHNOLOGY.

Second, in terms of agricultural and food inputs, there seemed good reason to think that the time was ripe for adoption of new technologies during the late seventies and eighties. Since the early eighties the agrochemical industry has been entering the mature phase of its development, with insufficient growth in world-wide markets to fund increasingly expensive R&D. New biotechnology was seen by some multinational companies as providing the springboard to set them off on a new growth curve and to prevent their 'decline' to producers of commodity chemicals (Tait et al, 1990). MNCs were therefore in a position of having to integrate new biotechnology products alongside an existing product range. In some cases, development of the new technology implied that old technologies would be made obsolete (i.e. development of insect resistant plants or microbial pesticides). In other cases, MNCs would be able to create synergy between different generations of technology as in the case of herbicide resistant plants. DBFs hoped to exploit niche markets that were too small or specialized to attract MNCs or to be able to retain control of a major new product and grow very rapidly as a result (Office of Technology Assessment, 1984). A whole range of factors discussed in the following chapters have made the actual path of innovation much more problematic than the predictions based on this reasoning indicated. The study indicates that, in a number of cases, MNCs were unwilling to undertake the economic or political risks involved in developing technology and that while DBFs where committed in theory to radical innovations, a number of internal and external constraints suppressed ambitions.

1.2.3. MICROELECTRONICS AND STRUCTURAL CHANGE.

Biotechnology came hot on the heels of vast changes wrought by the new microelectronic techniques. It was compared with microelectronics and both, along with new materials, were seen as important technologies in future industrial sectors (Roobeek,1987). Freeman and Perez considered that biotechnology could be one of the 'core' technologies in the fifth Kondratieff cycle (Freeman and Perez,1988). In some cases, the comparison went beyond the general speculation that the technologies would both somehow lay the basis for the 'second industrial revolution' or changes in techno-economic paradigm. Yoxen considered that the technologies might be developed along similar lines and that the new paradigm created by micro-electronics would also give direction to biotechnology.

> "We are now at the stage where merely thinking of organisms as programmed systems is giving way to the activity of reprogramming them. Scientists can now intervene in nature, constructing to order, as a microchip designer might decide what functions to realize in a piece of silicon, or a computer engineer select a range of modules with which to build a data-processing system. The analogy is not trivial. As microbiology becomes industrialized as biotechnology, that kind of construction activity, which has already shown its prodigious potential in micro-electronics, computing, robotics and systems engineering, will take the foreground in the life sciences. As in the field of inanimate hardware, it is astonishing what becomes possible when you start combining modules and functions"
> (Yoxen,1986:30).

Thus, it was thought that what could be done with microchips could also be achieved with living organisms.

1.2.4. SMALL FIRMS AND THE CRISIS OF FORDISM.

Fourth, the emergence of biotechnology was linked with small innovative science firms at a time when the role

of small firms in industrial advanced economies was being reevaluated. Indeed, the comparison with microelectronics also revolved around the role which small firms could play in developing technologies. Biotechnology innovation during the seventies and eighties took place in both Multinational corporations (MNCs) and Dedicated Biotechnology Firms (DBFs), the latter often set up by university researchers specifically to exploit new scientific opportunities. Biotechnology was closely associated with scientific discoveries made in university laboratories. University scientists, looking for commercial success, research establishments and entrepreneurs have been important agents in trying to establish commercial outlets and develop the technology. Events in the electronics sector, where some small companies innovated rapidly and very successfully, forcing competition and change led a broad range of business people and academics to reevaluate the role of the 'heroic entrepreneur'. With this renewed interest in Schumpeter's work on 'creative destruction', the importance of small firms in initiating innovations in the new areas became apparent. Moreover, the association of new technology and small firms seemed promising to many. Piore and Sabel wrote enthusiastically about the Second Industrial Divide that would signify the end of mass production as the dominant principle of industrial organization and the emergence of flexible specialization and smaller production units (Piore and Sabel, 1984).

It became apparent during the 1970's and 80's that western industrialized countries no longer enjoyed unchallenged industrial and economic supremacy. Economic difficulties in the United States and Western Europe were highlighted and compounded by Japan's astounding rise as an industrial power. While western governments focused on trying to resolve problems by disciplining labor and with various types of monetary policy, academics and business

people increasingly identified problems in terms of industrial structure and an inability to innovate competitively.

The French Regulation School (FRS) and Neo-Schumpetarian thinkers such as Freeman and Perez (1988), developed new ideas about the interaction between economic, technological and social and political factors. They suggested that a specific regime of accumulation governed different periods of capitalist development. Harvey summarizes the FRS approach:

> A regime of accumulation describes the stabilization over a long period of the allocation of the net product between consumption and accumulation; it implies some correspondence between the transformation of both the conditions of production and conditions of reproduction of wage earners. (Harvey, 1989:121)

FRS thinkers also highlighted the importance of social and cultural factors in creating 'regimes of accumulation'. They diagnosed the current crisis as resulting from the breakdown of the Fordist regime of accumulation and analyzed the future either in terms of Neo-Fordism (which involves changing practices, but remaining within the broad boundaries of the Fordist paradigm) or various Post Fordist scenerios (involving a more radical shift away from Fordist norms) (Nielsen, 1992).

The crisis in mass production derives from rigidities associated with Fordist production techniques (Lipietz, 1987, Aglietta, 1987). FRS thinkers identified efforts by Western producers to increase 'flexibility' and now forms of flexible accumulation.

> "[Flexible accumulation increases flexibility]...with respect to labor processes, labor markets, products and patterns of consumption. It is characterized by the emergence of entirely new sectors of production, new ways of providing financial services, new markets, and, above all, greatly intensified rates of commercial, technological and organizational innovation". (Harvey,1989:147)

FRS thinkers saw the crisis provoking changes in Fordism. Some perceived that there would be quite high levels of continuation between Fordist regimes and their successors, others saw a more radical shift. In addition to analysis of pervasive change from this quarter, Neo-Schumpetarian also thinkers saw widespread changes in technical, economic and social spheres (Freeman and Perez, 1988).

Piore and Sabel share some common ground with these authors. Their analysis differs in some fundamental ways, however. They see the future in terms of a Second Industrial Divide and the emergence of a radically different production structure based on flexible specialization, emphasizing the central role of small production units. Piore and Sabel contest that niche marketing will be an important feature of the new industrial environment and that this, combined with new opportunities afforded by information technologies, will give small firms the ability to out compete large firms in many cases (Piore and Sabel,1984). Flexible specialization would incorporate the following characteristics; 'flexible' production, involving smaller batches of more specialized goods; new computer systems and managerial practices making production increasingly 'demand driven'; multi-skilled and more highly trained workforces contributing to continuous innovation and improvement in output; heavier reliance on science and technology in order to improve products, rather than concentrating solely on cost reduction; increased horizontal collaboration between

firms; 'just-in-time' production techniques that involve radically different approaches to stock holding and quality control. While some of these characertistics overlap with broader Post Fordist visions, flexible specialization places much more emphasis on smaller scale units and small batches.

References to places where more flexible production strategies were succeeding included Japan and the Third Italy (Harvey,1989; Best,1990).

Piore and Sabel's ideas have been widely criticised and shown to be limited to relatively few regions. Moreover, other writers have begun to make more sophisticated distinctions between flexible specialization and Post Fordism (Nielsen, 1992). These distinctions are based partly on the observation that while the Third Italy may conform to Piore and Sabel's notion of flexible specialization, Japan does not. While Japan displays Post Fordist characteristics (new work organization, different forms of collaboration between firms, smaller batches, etc) it is still dominated by large producers. Thus, the point has been made that Post Fordism should not be equated with flexible specialisation; the later only applies to a few cases, while the former term encompasses a wider range of changes in social, economic and technical environments. Freeman and Perez characterize some aspects of this broad shift to new industrial formations in the following way:

> ...a growing search for new social and political solutions in such areas as flexible working time, shorter working hours, re-education and retraining systems, regional policies based on creating favorable conditions for information technology (rather than tax incentives to capital-intensive mass production industries), new financial systems, possible decentralization of management and government, and access to data banks and networks at all levels and new telecommunications systems" (Freeman and Perez, 1988:61).

This set of debates, then, constitutes the fourth reason why biotechnology was viewed with such excitement. Two main points are particularly relevant; the renewed interest in small firms reflected well on DBFs and the identification of technology as an important part of structural change made biotechnology, along with its big brother, microelectronics, seem like a miracle to some and a menace to others but in any case a significant phenomenon. Thus, at a time when Western economies were undergoing considerable change, biotechnology, along with new materials and microelectronics, were identified as technologies congruent with socio-economic conditions that would, in turn, be key players in shaping the future (OECD, 1988, Roobeek,1987).

'Global' analysis is usually of limited help when applied to specific cases and this instance is no exception. One of the aims of this thesis is to investigate the extent to which sectorally specific factors contribute to an understanding of how and why innovation occurs in particular ways. This is not to say that biotechnology will not be an important future technology, or that it can be viewed in isolation from structural and global trends, rather that the logic of its technological trajectory cannot be deduced from the pattern of other technologies' entry to the world; the interaction between 'the general' and the particular properties of the technology create a different story in the case of biotechnology, than for instance, new materials or microelectronics.

In the case of biotechnology, aspects of wider economic restructuring did, of course, have concrete consequences on the rate and direction of innovation. The type of restructuring which was taking place in many western capitalist countries during the eighties involved increased privatization and an effort to expand the rule of

the market into new areas. In the UK, for example, new efforts to make universities correspond to the 'economic needs' of society, meant cutbacks in government funding and encouraged academics to turn to the business community for money. Biotechnology, born in university labs, was marketable and thus became a vehicle whereby universities could commercialize their activities (Webster and Etzkowitz,1991). Nevertheless as the following chapters demonstrate, the rate and direction of innovation has been patchy. The interaction between general trends and specificities related to the technology and particular settings is immensely complicated.

The following section briefly examines some of the principal theoretical and policy perspectives that have been used to understand and guide innovation and their relation to this study. Theoretical perspectives on innovation will be further discussed throughout the thesis and in particular in chapter 7.

1.3. THEORETICAL CONTEXT.

Schumpeter distinguishes between invention (an idea or a sketch, or a model for a new or improved device, product, process or system) and innovation (the first commercial transaction involving the new product, process, system or device) (Clark, 1985:96-97). The relationship between science and invention is often very straightforward and direct. The step between invention and innovation is a more complex one, which by definition involves social and economic factors rather than exclusively technical considerations. Innovation involves socio-economic institutions such as firms and markets. Additionally, innovation increasingly involves the state and international governmental bodies, such as the EC (in funding R&D, regulating products and setting patent protection standards, etc.). Moreover, the techniques and

products of innovation are both shaped by and in turn shape societies. Thus, there is an intimate and complicated set of relationships between technological innovation, innovating institutions, public policy, cultural practices, social and political pressure (Roobeek,1987).

The nature of innovation, its relationship to socio-economic factors and its role in creating economic success has been in the past relatively understudied, particularly within the realm of economic analysis. A number of excellent critiques of Neo-Classical economics identified crucial gaps in the theory and developed new research paradigms. A fundamental problem of the Neo-Classical approach is that it considers technological change as *exogenous* to the economic system. This assumption makes technology an independent variable quite unrelated to the dynamics of the broader system. Innovation and technical change are, in the Neo-Classical tradition, seen as shifts in the production function curve. Here, production in the firm is conceptualized as the combination of inputs or 'factors of production', usually labour and capital. The technology used at any one time determines the techniques available for production and thus also determines the maximum level of output which can be obtained from a given level of inputs.

> "A technique is therefore effectively defined as a particular combination of factors of production. Among the available techniques the firm will choose the one which, given existing factor prices, minimizes total production costs" (Coombs et al,1987:25).

Thus, the Neo-Classical approach 'assumes' that the generation of technology is unproblematic, and diffusion is an automatic process, taking place among 'perfectly' informed producers who adopt on the basis of price efficiency. Whereas Classical approaches acknowledged the importance of context and institutions in the generation

and diffusion of technology, Neo-Classical approaches claim that the free market ensures successful innovation.

This approach ignores the thorny problem of why firms would naturally innovate at an 'appropriate' or socially desirable level. As Schumpeter recognized, profit-maximizing firms will normally prefer others to undertake costly research, rather than take on the risk and cost themselves (Schumpeter, 1947 and 1961). Walsh summarizes some other problematic Neo-Classical assumptions which ignore some basic characteristics of technological change and innovation in 'the real world':

> The assumption that information about the market is available, reliable and accurate, whereas it is often impressionistic and patchy.
>
> That the market and competitors can be defined, whereas market boundaries are often unclear.
>
> That supply and demand are stable relative to one another, whereas they are often changing quite rapidly.
>
> That firms make decisions that are objectively rational in an economic sense, whereas competitors' behaviour is often economically "irrational", rationality is bounded and search routines are limited (Walsh,1991a:7).

The numerous difficulties with the Neo-Classical model became more and more apparent during the second half of the twentieth century.

The Second World War represents a turning point in attitudes toward science and technology. "Government officials and scientists were equally impressed by the part research and development had played in winning the war [and] saw clearly the potentialities for peace-time development" (King, quoted in Massey et al,1992:66). While the potential was recognized and massive increases in R&D spending followed World War II, it became apparent that greater spending did not always lead directly to increased

growth (Coombs et al, 1987:4). Thus, during the nineteen sixties and seventies, policy, particularly under Labour governments in Britain, began to reflect the concern with linking science, technology and innovation (Coombs et al,1987, Massey et al,1992). The problem was seen in linear model terms; the challenge was to translate British excellence and inventiveness in science into successful innovation. The model identified 'science' as activity which occurs in the remote halls of academe, a source of economic growth which needs tapping. The logic of the model is such that "Science leads to technology; basic research to development and diffusion" (Massey et al,1992:58). A social division of labour is implicit in the model, with "white-coated scientists" being conferred with high status, while

> "...as we move further along the innovation line, according to the linear model, we move further from the high-status work to work that includes more engineers, designers, technicians, craft and other production workers, and salespeople. Status, historically, has been associated with distance from direct production, sales, and manual work, and closeness to clean, white-collar lab-type environments" (Massey et al, 1992:58).

In line with this model, the thrust of government initiatives, therefore, was constructed to increase spending on science and R&D and close the gap between university based research and industrial concerns. However, attempts to intervene in a more 'hands on' manner in the private sector were strongly resisted, thus,

> "In the 1960s and 1970s, as in the early post-war Labour government, though state funding was welcomed, any attempts to intervene actively to change the nature of British industry were resisted strongly by industrial owners. So attempts to pull together the stages of innovation in the UK led to further separations. Thus the introduction of management education in universities and polytechnics emphasized general management over management of production processes. And investment in universities, government research labs, nationalized industries, military and nuclear industries, though it produced islands of R&D excellence and career paths for another large group of post-war graduates in science and technology...always came up against the wall of a significant section of private industry that neither invested nor wished to invest" (Massey et al,1991:69).

Massey et al carried out extensive research on Science Parks, which embody one of the latest attempts to link science and industry. Science parks, which first emerged in the US, offered a "new variant on the linear model of innovation". The science park is consistent with the linear model "based as it is on academe as the source of research ideas to be developed in park enterprises and manufactured elsewhere" (Massey et al,1992:71). It differs in that in some respects it is closer to a Post Fordist or flexible specialization type of model mentioned earlier in the chapter which involves small, dynamic and innovative companies engaged in niche marketing (Massey et al,1992:71). Thus, whereas other attempts to integrate science and industry were aimed primarily at vertically integrated industrial corporations, science parks invoked "the principle of the individual sci-tech entrepreneur". Instead of trying to take science to industry, this was an attempt to move the other way along the line and move commercial interests closer to science and academia.

A number of constraints to successful innovation in firms located in science parks existed. One of the

problems was that firms failed to develop 'leading edge' technologies.

> "Many science-park enterprises operate under extremely short-term market pressures, drastically constraining their ability to undertake long-term and risky 'leading edge' innovation. In practice, many see themselves proudly more as shorter-term and smaller-scale commercialisers and advisers about technology than as leading-edge innovators" (Massey et al,1992:73).

Although the majority were not based on science-parks, the firms I visited, like the companies studied by Massey et al, found it impossible to fulfill their assigned role in the linear-model; DBFs found that the lack of long term funding, difficulties in negotiating regulatory hurdles, lack of management experience and uncertainty about how to deal with an uncertain patents situation, left them unable to develop more radical and higher-value techniques. Additionally, companies considered in both Massey et al's study and this research lacked 'tacit' knowledge about technical aspects of the development process; thus knowledge about 'scaling up' for example, was a problem in a number of cases. The problems experienced by DBFs and the small companies in the Massey et al study point to inadequacies of the model.

An additional problem with the linear model which applies to both large and small firms, is that it largely overlooks sectoral differences in the way in which innovation happens (Pavitt,1984). Nor does it incorporate the numerous factors, internal and external to firms which can influence innovation and it disregards the fact that the starting point for innovation is not necessarily basic science, but sometimes the shop floor (Vincenti,1984).

There has been increasing recognition among policy makers, academics and business people that innovation and technological change need to be analyzed rather than simply

assumed as an extension of scientific invention which will be guided by the market. Analyzing related problems in terms of inadequacies of purely market based solutions and speaking specifically about biotechnology, Webster writes,

> "There is little point in having policies for technology if, at the same time, policies for industry are ignored: as recent analyses have shown...the market is a relatively poor mechanism through which the exploitation of R&D is effected (Webster,1990:382).

Analysis of institutions, such as firms, in which innovation occurs has been inadequately conceptualized in a range of theoretical approaches to innovation. The FRS approach provides a valuable, but very general, methodological and theoretical framework which links technological trajectories and patterns of production and consumption. Perspectives developed in the field of social shaping of science and technology, while useful, tended to focus on the technology itself and ignore the role of the firm in innovation. Sectoral perspectives, for instance those articulated in widely referred to work by Pavitt (1984), are important in that they demonstrate that sectoral characteristics impact on the rate and direction of innovation. However, various authors (Coombs and Richards,1991, Amendola and Bruno,1990) have pointed out that the approach does not account for differentiation amongst firms within sectors the different ways in which firms respond to changing sectoral characteristics. In recent writings, Coombs and Richards (1991) Green (1991) and Amendola and Bruno (1990) have attempted to introduce new perspectives which incorporate more formal analysis of the firm and innovation.

Additionally, recent research on biotechnology innovation has also stressed the importance of institutional factors, public policy and culture in shaping markets and therefore demand for innovation (Green,1991 Walsh,1991b, Tait and Levidow, 1992, Tait et al,1990).

These factors are indeed important in biotechnology innovation as will be seen in the following chapters.

Theoretical perspectives are clearly in need of further development. Adequate theoretical frameworks for innovation should incorporate broad perspectives on the interaction between technology and production and consumption patterns, but also recognize the centrality of the firm as the principal innovating institution in advanced capitalist societies. In an article which reflects a number of key features of this approach, Amendola and Bruno (1990) write that innovation must be seen as a process of change in both the firm and its environment. Additionally, the specificity and particular characteristics of technology must also be recognized. While this thesis does not attempt to construct such a theoretical edifice, the information generated by the study could contribute to such an effort.

1.4. FRAMEWORK FOR THE THESIS.

The research involved in this study, carried out over two years between 1989-1991, exposed a complex and uneven terrain of biotechnology innovation. Biotechnology seemed to 'fit' with more general trends in the global economy; it was science and technology intensive, its unique technical properties gave new possibilities for specialization, flexibility and control. Small new biotechnology firms appeared to embody a number of Post Fordist ideals; they promised to be very innovative, close to academe, cross-sectoral, specialized, flexible and focusing on niche marketing by introducing high value/low volume new products. However, the thesis argues that these firms often failed to translate research projects into innovation at the development stage because there was not the 'know-how' or facilities within firms needed to generate products, nor were there institutional supports which could

have helped them prosper (Webster,1990, Tait et al, 1990, Oakey et al,1990).

MNCs, examined in chapter 4, were pursuing a wide range of different strategies. At one extreme, one of the companies examined had restructured itself largely on the basis of biotechnology and was fully committed. At the other extreme, one company had largely divested itself of mainstream agricultural biotechnology. Another company was pursuing a very cautious strategy and was convinced that agricultural inputs would be dominated by the continued use of chemicals for the foreseeable future. Regulations, and the relatively low value nature of agricultural markets, patent legislation, organizational and cultural aspects of firms and political perceptions, both internal and external to the firm all influenced the rate and direction of innovation in both DBFs and MNCs.

Thus, while it seemed to many that biotechnology would offer rapid solutions to growth problems within the agricultural and food sectors and in more general terms would contribute to industrial growth in the Western world, the actual rate of innovation has been slower than anticipated. The path of innovation seemed blocked and the prognosis about future developments vacillated during the eighties; on the one hand there remained a fascination with the techniques and on the other many in the business community became daunted by enormous technical and non-technical challenge involved in innovation. Whilst there have been some significant process and product innovations during the eighties, there have also been significant problems.

Various theoretical perspectives, as suggested in the previous section, can contribute to an understanding of biotechnology innovation. First, I argue that in order to understand the dynamics the innovation process it is necessary to move away from the linear model as an

interpretative or predictive guide. Dosi, (1988) in a review of the innovation process has put forward five 'stylized facts' or propositions about innovation:

1. Innovation involves a fundamental element of uncertainty.
2. Contemporary technological innovation is increasingly reliant on advances in scientific knowledge.
3. The increasing complexity of research and innovative activities militates in favor of formal organizations (firms' R&D labs, government labs, universities) as opposed to individual inventors.
4. Significant numbers of innovations are originated through 'learning by doing' and 'learning by using'.
5. Technical change is a cumulative activity.

The first three points do not necessarily stand in contradiction with the linear model of innovation (Massey et al,1992:79). The fourth and fifth, however, do not fit as well.

Dosi's five 'facts' can provide insights into the specifics of biotechnology innovation in both large and small firms. Their relation to the findings will become apparent in the following chapters and connections will be explicitly made in chapter 7. A very brief summary of connections to be made in following chapters is as follows: Points 1 and 2 clearly apply to biotechnology innovation which is characterized both by high levels of uncertainty and a sustained attempt by firms to get closer to the science base which they perceive will give them competitive advantage. Point 3, contributes to our understanding of why many DBFs have found successful innovation such an elusive goal. Teece's observations about how possession of complementary assets such as marketing and distribution facilities, contribute to large firms gaining the most from innovations, whether or not they have actually developed them, are also important in this respect (Teece,1986). However, as chapter 4 demonstrates, the increasing

complexity of innovation also posed serious challenges for MNCs. Rothwell summarizes some of the main elements of the complexity which characterize the 1980s and early 1990s.

> "During the...period (early 1980s-1990) the situation appears...complex with a broader combination of central themes: de-diversification; technological accumulation; inter-firm collaboration; and global strategies" (Rothwell, 1991:15).

Point 4, stresses the importance of 'tacit' knowledge in innovation. This concept sheds light on both large and small firms in the study in a number of important ways. For example, DBFs had problems in developing and marketing products because of lack of experience and large firms found that they could not respond as quickly as smaller counterparts who had knowledge embodied in individual members of teams and scientific culture and a 'feel' for biotechnology. It will be argued that acceptance of the idea of 'tacit' knowledge and 'learning by doing' has both management and public policy implications, which have been recognized in other contexts, for example, Japan and South Korea[3]. Dosi's fifth fact is also an important insight; the contention here is that because technical change is cumulative, "What the firm can hope to do technologically in the future is heavily constrained by what it has been capable of doing in the past." (Dosi, 1988:225) Thus it takes time for firms to learn not only about scientific properties but also about technical issues associated with development and the social frameworks associated with different technologies; how to deal with patents and regulations for example.

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[3] See Alice Amsden, (1990) 'Third World Industrialization: 'Global Fordism' or a New Model?' for an analysis of S.Korea's rise as an industrial power. Amsden argues the country has pursued a strategy of 'learning by doing' and this is an important component of its rapid industrialization.

Points 4 and 5 give rise to a number of complicated questions about university/industry relations and inter-industry collaboration, analyzed in chapter 5. If the analysis is accepted it implies that firms must manage their collaborative efforts carefully and that successful technology transfer cannot simply constitute buying discrete pieces of information. However, precisely because innovation is cumulative and is a process of learning by doing, large established firms will depend to some extent on links with the outside so that they may break with the past. While large firms had numerous advantages over smaller counterparts, chapter 4 demonstrates that firms can be constrained by past activity and must identify ways to change and to 'unlearn'.

The findings of the thesis have complicated implications for Post-Fordist theory as it relates to innovation. While the issues are apparent in various places in the thesis, they are directly discussed in much greater detail in chapters 3 and 7. While the study concurred with a number of points raised by Post-Fordist theorists, predictions that small firms would play a leading role in final product innovation are questioned. Many managers interviewed agreed that production was becoming increasingly science and technology driven and that the pace of change was increasing rapidly. Post Fordist thinkers predict that this would lead to increasing collaboration between large firms and specialized producers. While new forms of collaboration were being sought after by many of the firms examined in the study, four out five of the large companies either had very few collaborative ventures with DBFs or did not pursue these types of collaboration at all (although as has been suggested, they may have benefited from increased collaboration).

In more theoretical terms, there are curious ambiguities in some of the Post Fordist writing. First, along with those who have shed light on the failings of the linear model, Post Fordist theory suggests that "...innovation requires the integration of *all* skills (marketing, design, production and R&D) at *all* stages of the process" (Massey et al,1992:71). The two theories share common ground in suggesting that R&D functions and further downstream elements of the production process need to be much more tightly linked than often occurs in more traditional Taylorist firms. However, this sits somewhat uneasily with some of the flexible specialization claim that small, flexible producers are the innovators of the future and that high levels of vertical integration are an outmoded Fordist phenomenon. These small firms are often unable to get significant final products to market and are in many cases far removed in terms of geographical and cultural space from final product developers.

These points relate to factors influencing the generation of innovation at the level of firms, which it has been argued constitute key innovating institutions. However, other factors which directly affect demand and markets, and which contribute to the shaping of markets, must also be taken into account. Firms do not operate in a vacuum. Thus, I will argue that in order to see the whole picture of biotechnology innovation, consideration must be given to market and price structures in the agricultural and food sectors. Technology and innovation are related to wider social, political and economic processes. This is discussed in chapter 5 which focuses on institutions and markets. Chapter 6 examines non-market factors such as regulation, patent legislation, public opinion. These non-market forces are social and political constructs which shape demand and consumption patterns. These factors cannot be tacked on the end as 'additional factors' in

studies of innovation, they are integral to the process. Firms have responded to these influences in a number of ways including changing their production strategies and becoming actively involved, as political actors, in shaping markets. For example, a number of large MNCs involved in biotechnology innovation set up an organization called the Senior Advisory Group on Biotechnology (SAGB), among other things in order to lobby for a European regulatory regime which would suit their needs. Other firms have been engaged directly or indirectly in trying to win over the public and professional bodies to biotechnology. The implication here is that successful innovation is not only the result of having the right production environment, but is also related to appropriate external environments (regulations, patents, attitudes of policy makers, relevant professional bodies and consumers). Moreover, firms must be understood as political and social as well as economic actors. Amendola and Bruno's (1990) characterization of innovation as a process of change in both the firm and environment clearly applies here.

This chapter outlined the issues considered in this thesis and the theoretical frame which guides the study. The following chapters attempt to shed light on the thesis objectives as defined at the beginning of the chapter. Key issues to be discussed include the following: An examination of social, political and economic factors influencing innovation; consideration of the institutional factors that affect the rate and direction of change; the critique of the linear model of innovation and related observations about Post Fordist theory. The theoretical issues raised in the final section of the chapter will be raised at appropriate points throughout the thesis and will be considered in more detail in chapter 7.

CHAPTER 2. AN INTRODUCTION TO THE COMPANIES AND A DISCUSSION OF METHODOLOGY.

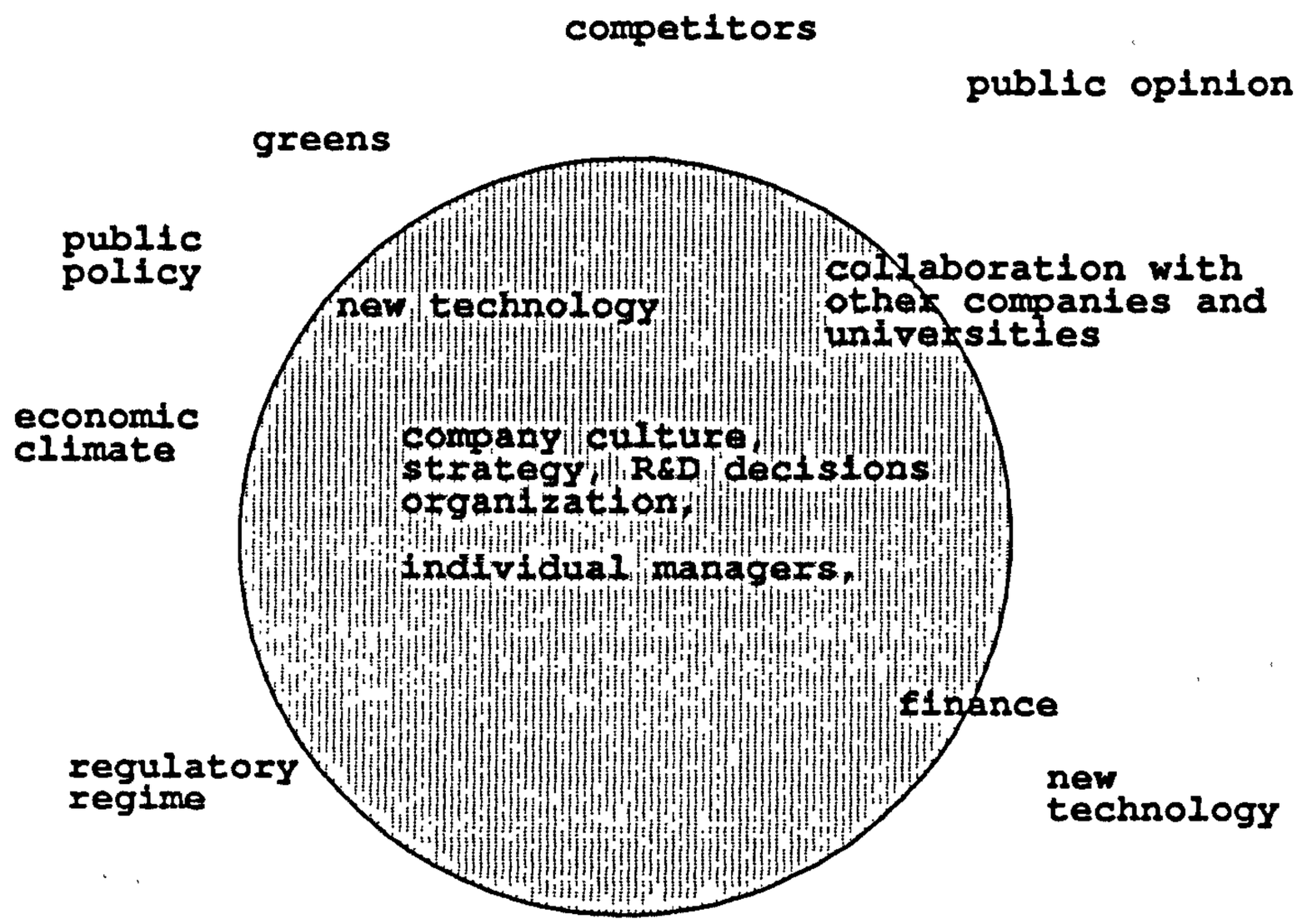
This chapter discusses aspects of methodology and provides details of interviewing structure and the companies involved in the survey. Methodological and theoretical perspectives are not separate issues. Therefore, Section 2.1. discusses both methodology and theoretical underpinnings to the approach taken in this study. Section 2.2. explains more practical details of how interviews were carried out and techniques used during the interviews. Section 2.3. provides details of the companies visited.

2.1. THEORY BEHIND THE PRACTICE.

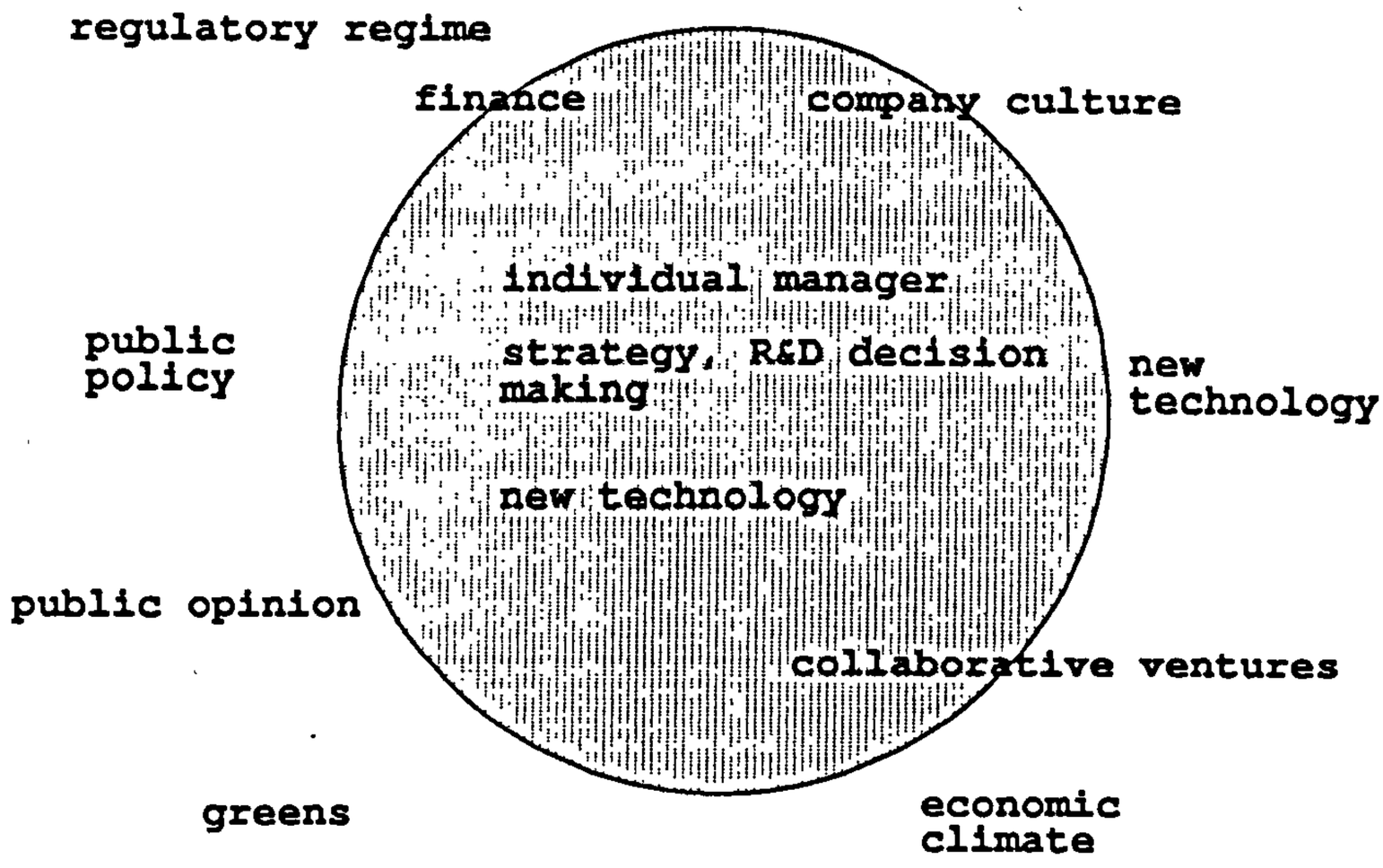
The study was designed in order to further understanding about what factors influence managers' strategic decision making about biotechnology innovation. As I aimed to find out as much as possible about the way managers perceived biotechnology innovation currently, in-depth interviewing was the most appropriate technique. Although the unit of analysis was a firm operating within a specific sector, and the focus on company strategy, it was not possible to interview an organization in order to find out its views. Organizations are made up of individuals and therefore the entry point to the study was the individual. Organizations and individuals within them are not the same thing, nor can organizations be reduced to the people who constitute them. Harmony between managers' views cannot, of course, be taken for granted and

organizational goals and formal strategy may be interpreted in varying ways in practice. Nor can firms be considered in isolation. R&D decision making and strategy in a company is a product of this interaction between manager, firm and external environment.

The following systems diagrams (Systems Diagrams 2.1. and 2.2.) portray elements in the relationship between manager, firm and key elements commonly seen as affecting innovation in the external environment.



Systems Diagram 2.1. Large Firm.



Systems Diagram 2.2. Small Firm.

The logic behind the diagrams is the level of control exercised by the firm (the system) over factors which affect its operation. The manager operates within the context of the firm and is therefore represented within the boundaries of the system. While the firm has ultimate control over any individual manager, the relationship is of course a two way process; the manager can, and in most cases is expected to, influence decisions in the firm. Culture and organization are more problematic. First, there is perhaps a problem in using the notion of 'control' in relation to difficult and elusive concepts such as culture. It maybe more accurate in some circumstances to view the culture as having control over the company. Nevertheless, the concept lies firmly within the boundaries of the firm and can be seen as ultimately something which the firm can, given the desire, at very least alter and change. The second problem is that the interaction between culture and organization and managers will differ; the size and nature of the firm and his/her place in it will affect the relationship between these factors and the manager. A top manager in a small firm (diagram 2) will have more

influence over culture and organization than say, an R&D manager in a large firm. However, the firm, (rather than the manager within the firm) being smaller and more vulnerable has *less* control over culture and other factors. (diagram 2). Diagram 1, representing the situation in a large firm, has culture within the boundaries of the system, indicating the greater control which large firms have over factors influencing their operations. The external environment, within which the firm operates, affects the system, but the system, the firm, does not have control over it. Firms may try and influence such factors as patent legislation and regulatory regime, but will have virtually no control over these factors as an individual firm. The firm will have more some control over finance and collaboration with other firms and universities, although not complete control, thus these concepts appear on the boundary of the diagram. New technology appears both on the inside and outside of the system boundary in both diagrams. This is because new technology generated within the firm can be controlled, whereas new technology generated by other actors cannot.

Within the realm of systems analysis, Ackoff makes a distinction between 'problems' and 'messes'.

> "Managers are not confronted with problems that are independent of each other, but with dynamic situations that consist of complex systems of changing problems that interact with each other. I call such situations messes. Problems are abstractions extracted from messes by analysis; they are to messes as atoms are to tables and chairs."[4] (Ackoff, quoted in Rosenhead,1989:10)

Thus, as a researcher, I constructed a problem, or, more accurately, a set of questions, but had to try and understand the messy situation in the firm. The method of

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[4] Ackoff is writing in critical mode; he is outlining a number of the problems associated with traditional approaches used in Operational Research (OR).

loosely structured in-depth interviewing reflected a desire to tackle the mess from the managers' holistic perspective while at the same time getting relevant information about the problem (R&D and Strategic decisions at the level of the firm).

Giddens, (1976) in his work on the limits of interpretive sociology argues that it has failed to conceptualize institutional analysis adequately and that this has caused a number of problems in relating 'meaning' to 'action' and in distinguishing between intended action and unintended outcomes. (Giddens,1976:158) He says,

> "The failure of the Anglo-American philosophy of action to develop a concern with institutional analysis is reflected in an over concentration upon purposive conduct. Thus many authors have been inclined to assimilate 'action' with 'intended action', and 'meaningful act' with 'intended outcome'; and they have not been much interested in the theoretical analysis of the origins of the purposes that actors endeavor to realize, which are assumed as given, or the intended consequences that courses of purposive action serve to bring about" (Giddens,1976:156).

Giddens strikes at the heart of a long-standing sociological debate about relationships between intention and outcome and subjective truth and action and objective reality. The question of the relationship between subjective meaning and objective reality is a key problematic of sociological method and theory and it is not the aim of this thesis to summarize or explicate the debate. However, there is no avoiding the question of whether talking to managers and trying to establish how they construct 'meaning' and strategy (or how they choose to describe their world to inquisitive researchers) would get us nearer to learning about the action and practice of innovation. A number of points are relevant here.

This study was not limited to understanding innovation on the basis of manager's perceptions. Attempts

have been made to consider the firm as a whole and also the environment in which the firm operates. However, the main 'field work' tool consisted of in-depth interviewing. The limits of this methodology and the way in which findings are used in the study requires some discussion. I am not claiming that managers' perceptions necessarily reflect the reality of the firm, nor that strategy as envisaged by individual managers is necessarily equated with what the firm actually does. Nor am I suggesting that intended action can be equated unthinkingly with outcome. Indeed, unintended consequences have played an important role in some aspects of biotechnology innovation and these will be made explicit in the thesis. Moreover, this study is based on a case study approach where sample size imposes limits on the generality of claims which can be made. A number of concepts are relevant to the methodology used. First, with regard to the relationship between subjective understanding and objective reality I subscribe to the view that modern history does not move according to some unalterable 'logic of capitalism', or 'invisible hand of the market'. Nor do I believe that a voluntaristic approach which ignores structural constraints is accurate. The 'logic' of capitalism is the combination of system requisites (the profit motive), institutional structures and subjective interpretation and action. There is no determining relationship involved. It is the interaction between these different levels of reality, and the way in which they break down into each other, which is important.[5] Thus, while the data generated from field work relate to

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[5] In some sense, this constitutes the core of the critique of neo-classical economics, which only gives credence to the operations of the market. Obviously, this position also differs from technological or economical determinisim, both of which can be found in various strands of Marxist writings, but which many would argue is not a necessary component of Marxist theory. See Nathan Rosenburg, (1982) for a discussion of marxist approaches to technology.

individual perception, the study attempts to incorporate some consideration of this interaction and reflects on implications for theories of innovation.

Second, the above point suggests a connection between interpretation (managers' understandings and action) and the pattern of innovation. A key point which should be mentioned here is the manager's place in the organization. Here, I have concentrated on developing a picture of biotechnology innovation from the perspective of managers of firms. Their 'meaning' is related to the 'action' of innovation, but within limits; their interpretation of events and their prescriptions, are filtered through the organization of the firm (Morgan,1986). The methods used by Pettigrew (1985) in his seminal study of ICI were similar to those used here, apart from the development of detailed accounts of the internal workings of the firm. However, particularly where I conducted a number of interviews within a firm, an overview has been produced in addition to individual assessments. Specifically, I aimed to understand the firm from different managers' perspectives, to understand organizational structures, the company's culture and organizational ethos and I also made distinctions, where it seemed appropriate[6] between managers' perceptions and prescriptions, the official 'line' taken by the firm and the action of the firm. Often managers themselves would make these distinctions explicit in the course of the interview. Interviews were backed up by reviews of company literature which reflects the organizational perspective, rather than the individual's

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[6] Obviously, the kind of impact that individuals had on their firm and vica versa depended a great deal on the context. For instance in a number of the smaller companies, individual managers, particularly if they were founders of the company had 'stamped' their companies in quite profund ways. Compare this with a lower level manager in a large MNC. The degree of influence which individuals have depends on the level of bureaucratization and their position in the organization Morgan (1986).

interpretation. Additionally, several interviews were conducted with other academics working on projects related to biotechnology, consultants and a leading journalist concerned with biotechnology. A literature search acted also as a check on the data.

In summary, the research used in-depth interviewing techniques to examine firms' strategies and strategic thinking and from those observations, combined with documentary research and additional interviews, drew conclusions about factors influencing the rate and direction of innovation.

The concept of strategy is important to the thesis. Moreover, the terms strategy and strategic decision making, as they will be defined here, bring together a number of theoretical points. The following assumptions, (adapted from Webster and Swain,1991) portray one view of strategic thinking and action:

A calculation of rational action by individuals or collectivities, recognizing, however, that what may be rational for the individual is not necessarily so for the collective;

Choice: i.e. there are alternative courses of action which are considered but dismissed as inappropriate. However, concepts of 'bounded rationality' and 'selection environments' (Morgan,1986) denoting limits imposed by external environments and structures in the latter case and of knowledge, experience and value systems in the former are also recognized.

Conscious agency and a sustained pattern of behaviour to achieve ends which can be conceived of in terms of Weber's purposive-rational and value rational forms;

Agency in the context of interaction (in this case, within the firm and with the external environment);

> Recognition that some have a <u>greater capacity</u> than others to choose a form of action (a strategy) which maximizes their interests (i.e. that some have more power and resources than others).

One of the problems with the concept of strategy is that it is always in firms' interest to portray strategic decisions as having been successful, thus managers may change accounts of strategy retrospectively if it failed. Although a surprising number of managers' admitted to their own and their company's errors of judgement, our approach was one of caution. Another related problem with using this concept of strategy is that not all behaviour or thought is rational. Strategy often at least partially results less from rationality and more from cultural attributes of the firm, combined with the neccesity of responding to changing economic conditions. Forces external to the firm which provoke change are considered in the thesis and in chapters 3 and 4 the concept of culture is introduced with respect to firms examined. In combining these different perspectives, I hope to avoid the problem identified by David Knights and Glenn Morgan (1990) whereby "...strategic analysis invariably slides either into voluntarism where there is an elevation of subjective intention or...falls back on structural determinations in which strategy is seen as a product of market forces." The thesis suggests that strategy, meaning longer term planning, is the outcome of rational, conscious thinking and non-rational thought and behaviour. Moreover, as already noted in the discussion relating to the systems diagrams it is a balance between factors internal and external to the firm.

Culture is an elusive and complicated concept and has been debated widely by academics (Thompson et al, 1990; Harvey, 1989). The concept is summarized in relation to companies by Nancy Foy in the following way.

"A company culture is the collection of its almost instinctive beliefs, allergies, heroes, villains, accomplishments, caveats and commandments Some of these like the neuroses of individuals, are so deeply rooted that their origins are lost in the mists of past events, while others have vivid, visible causes." (The Guardian, 2 September, 1981)

This description identifies possible roots of cultural attributes. While it touches on the intangible nature of the concept and the non-rational nature of much firm behaviour, it does not provide sufficient definition and its transposition of psychological constructs, applied normally to individuals, to organizations could be called into question. For the purposes of this study, it was necessary to 'operationalize' the concept by identifying specific, distinguishable characteristics. One of the companies I visited had studied the connections between corporate culture, values and strategy. They hoped to be able to decipher competitors' future actions according to value and cultural orientation. In one study, they attempted to identify corporate value systems. They did this by reading through competitor's published statements and annual reports identifying and counting key words and from this deducing broader cultural orientations. While this research project takes a different approach, the categories developed by company managers are useful ways of distinguishing between different companies' characteristics. The following list includes several of the categories which they used in order to differentiate between corporate values and one other (the last to appear on the list) which I have added and which relates to the specific concerns of this study:

- Security of profits
- Costs orientation
- Growth orientation
- Product excellence
- Consumer orientation
- Scientific and technological excellence

These attributes could be either 'cultural' or 'strategic' in the rational sense and the categories contribute to understanding differences between companies' orientations in a useful way. They will be used as descriptive tools in addition to other cultural characteristics, which encompass some of the more ambiguous elements incorporated in Foy's understanding of the term and which became apparent in interviews.

2.2. PRACTICE AND TECHNIQUES.

I conducted in depth, semi-structured interviews with middle and senior level managers in each firms. In a number of cases I was also given access to lower level managers and R&D scientists. This proved valuable; lower level managers are not so accustomed to being interviewed or talking about their work to outsiders and perhaps because of this they were keen to discuss their job and their perspective of the firm's strategies and decision making processes. Their accounts often painted a very different picture from that of high level personnel. For instance, it was not until I spoke with a relatively junior financial manager in one company that I learnt that a deadline had been agreed between funders and top management to give the company six months in which to generate a profit. If no profits were forthcoming, parts of the company would be sold off. In another instance a lower level research manager painted a picture of an organizational structure within the firm that was rife with problems, whereas more senior managers had described a much more harmonious atmosphere.

Interviews usually lasted between one and half hours and two hours and were tape recorded unless the interviewee objected. There were, perhaps surprisingly, very few objections to being recorded. I went into each interview

with a clear idea of areas which needed covering, but tried as much as possible to establish a relaxed, informal discursive mode rather than a question and answer session. The aim of the interviews was to get managers' accounts of factors affecting decision making about strategy and R&D within the firm. The interviewing situation is a complex one; it is impossible to interview with the purpose of extracting defined information and at the same time to let interviewees lead the discussion so that they are more accurately giving their own opinions and perceptions. Nevertheless, recognizing these boundaries and my own role in the interviews, I believe the loosely structured interviews gave a truer reflection of manager's priorities and concerns, rather than simply a reflection of my own perception of the situation. I also listened very hard, not only to the content of what the interviewee said, but also to the tone of voice and watched as much I could. Often when I realized that I had touched on a sensitive area I would make a mental note to come back to the subject, sometimes through a different line of inquiry later in the interview. Sometimes approaching the same subject from a different angle elicited slightly different reactions. Sometimes it was the same reaction but by leaving difficult issues to the end of the interview I could keep interviews relaxed for as long as possible. Interviews were later transcribed and content analyzed.

During the interviews, and later for the purposes of analyzing and presenting the data, I used a cognitive mapping technique called COPE. COPE is a qualitative technique which has been used extensively in consultancy situations. It was developed as part of a more comprehensive approach called Strategic Options Development and Analysis (SODA) to be employed by OR consultants (Eden,1989). It is based on Kelly's Personal Construct Theory and is designed to aid decision makers in problem solving. Eden, the originator of COPE says,

"The particular body of psychological theory is *cognitive* theory. It argues that human beings are continually striving to 'make sense' of their world in order to 'manage and control' that world. In this way it implicitly sees the individual as a problem finder/solver, using concepts rather than emotion to guide action. Therefore, it suits the particular purpose of working with individuals who are constrained by a need to *explain* their actions within their organizational world (Eden,1989:25).

Cognitive mapping, then, is a modeling technique which intends to portray ideas, beliefs, and cultural values and attitudes and their relationship to one another in a form which is amenable to study and analysis. It relates to the perspective taken in this study on strategic thought and action, in that it is based on the principle that while not all thought or behaviour is rational, people try to 'make sense' and construct rationality.

The technique was developed in consultancy situations and here interviewer and interviewee consult the map together at various points during the interview. This gives the interviewee the chance to see what he or she has said and the connections which are being made and in order that people can explain their ideas more fully. Used in this way COPE is thought to be a useful facilitative device (Eden, 1989) and goes beyond being a methodological tool. The interaction between interviewer and interviewee is analogous to the interaction between a counselor and client. The counselor tries to act as a mirror so that the client may look at their own world view with more distance and in this way reconstruct their beliefs, actions and feelings. COPE is a facilitative device which allows for this kind of reflective consideration.

I was not using the technique in a consultancy situation, therefore the aim was not to use the technique as a learning device for the manager, but in a more limited manner. I used COPE as a very useful way of collecting

data and as an analytical tool which would help to order data and therefore to better understand situations. Thus, interviewees did not consult maps during the interview, although maps were sent back to managers after interviews in order that they may comment on them.

The technique proved useful in the interviewing situation in that it painted a picture of the interview and pointed to areas which had not been talked about sufficiently or to connections which the manager might be implying. Thus, it helped identify gaps in interviews and served as a 'prompt' to ask follow up questions. It is also an extremely useful way of compiling and presenting data.

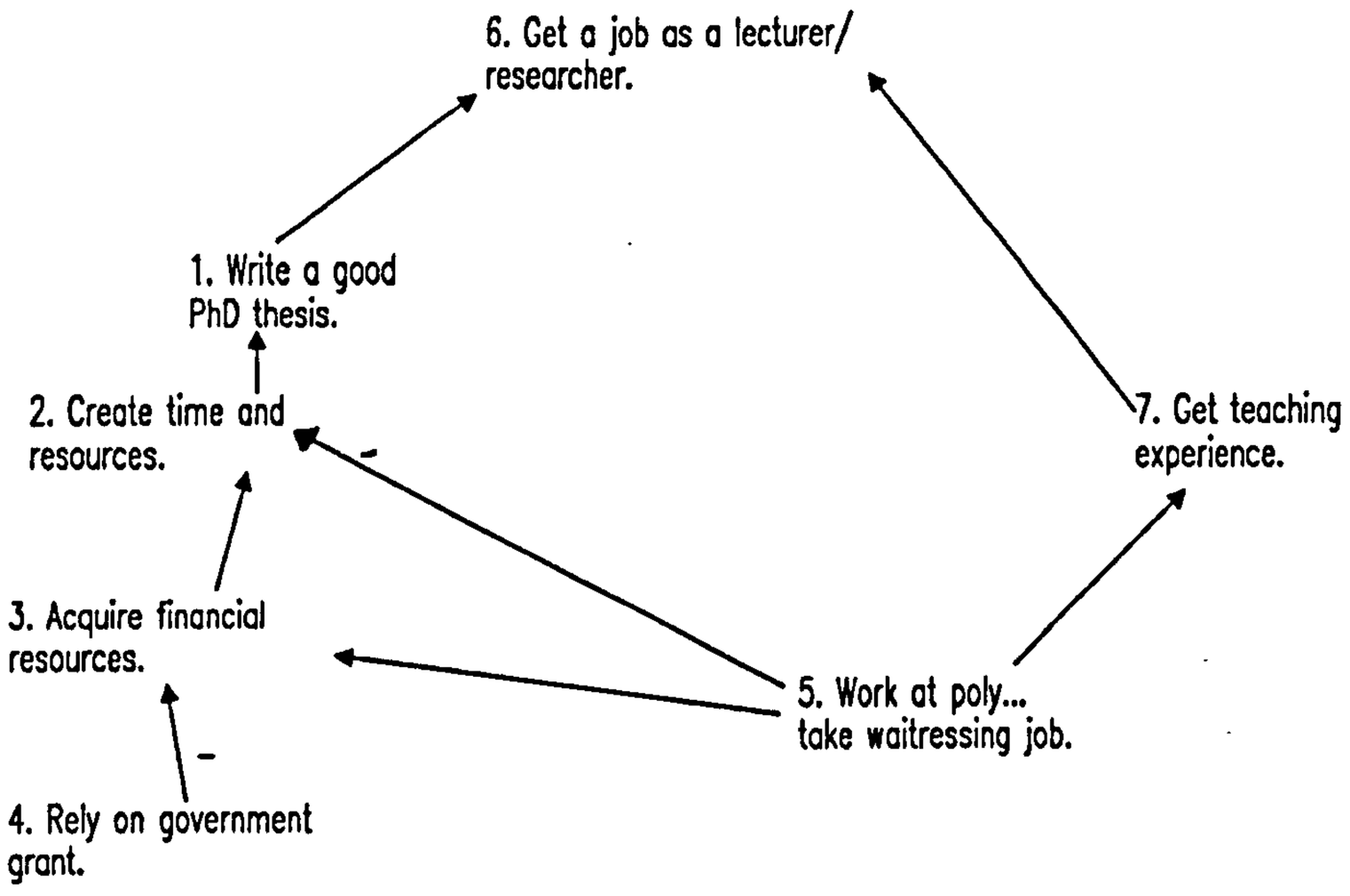
The following conventions were used in constructing the maps:

-ideas (concepts) are usually placed in a hierarchical format with high priority goals appearing at the top of the map.
-ideas are expressed as far as possible in the language used by the interviewee;
-where appropriate from the context of the interview, the opposite, negative pole of a concept (as envisaged by the interviewee) is indicated after the insertion of a dotted line;
-the arrows link lower level options to desired outcomes, or, in a similar sense, consequences to causes;
-a negative sign attached to an arrow indicates that the lower level concept links to the negative pole of the higher level concept;
-there is no significance in the numbers attached to each concept; they merely represent the order in which the concepts were entered into the computer. However, they are a convenient means of identifying concepts.

The following map (Cope map 2.1.) is based on an imaginary interview with a graduate student about to embark on a Ph.D. Initially, in the course of conversation the overall goal is defined by the interviewed in the following way, 'Write a good Ph.D. thesis' (concept 1). The interviewee then identifies a number of factors which will

enable her to realize this goal. 'Create time and resources' (concept 2) has a direct link with the ability to write the thesis. The interviewee, in response to questions identifies 'financial resources' (concept 3) as a particularly important resource and goes on to say that she has a government grant but finds this inadequate (concept 4) Because the government grant is thought to be insufficient and is expressed in negative terms, a negative arrow links concept 3 and 4. The interviewer then tries to establish what other options the woman has for earning or gaining more money. She says that she is considering taking on work as a part-time tutor in a local polytechnic (concept 5, connected to concept 3). Although this will cut down on the time available for the Ph.D. thesis, it seemed to her better than poorly paid waitressing work which was the other option she mentioned. Waitressing is incorporated as a 'rather than' (denoted by the symbol ..) in concept 5. Because the interviewee, however, considered that tutoring will cut down on time which could be used to work on the thesis, a negative arrow links concept 5 to concept 2.

The interviewer then looks at the map which has been constructed and asks the woman why she wants to write a Ph.D. The interviewee responds that she wants a Ph.D. in order to work as lecturer and researcher. Thus the top goal changes to 'Get a job as lecturer/researcher' (concept 6). The women then remembers another reason why she preferred to take a job as a tutor; she felt that teaching experience would enhance her opportunities of finding work as a lecturer later as she would have had some teaching experience. The interviewer adds the map, 'get teaching experience', (concept 7) and draws an arrow from concept 5 to concept 7 and from concept 7 to concept 6.



Cope Map 2.1.

2.3 INTERVIEW SCHEDULES AND BASIC DETAILS ABOUT COMPANIES INVOLVED IN THE STUDY.

This section provides details of how companies were selected for the study and basic details about the companies themselves.

I decided to limit the study to these two sectors for several reasons. Given the time and financial constraints some boundaries had to imposed; food and agriculture overlap and, of course, have common characteristics. These two sectors are subject to a more interesting and varied range of constraints on their activities than the pharmaceutical sector. My personal interest and experience was also more oriented towards the food and agricultural sectors, rather than looking at the pharmaceutical sector or applications of biotechnology feeding into other industrial sectors.

I used the Biotechnology Industry Association's Directory of British Biotechnology, 1988-1989 to select small biotechnology based firms working in the areas of

food and agriculture. I contacted managers in firms fitting this description in the directory (approximately 20) by phone or letter. A number of the firms, after initial contact had been made clearly did not fit the specification; some were obviously operating very much on the periphery of the types of biotechnology in which I was interested and were therefore rejected. A number were fully owned subsidiaries of multinational corporations and were also not included. I wanted to select companies that had retained a level of independence. For many DBFs, however, independence is not a clear cut issue. Very few companies do not depend on MNC investment in some way and thus, very few are not directed by MNCs to some extent. This was an important issue for DBFs and will be discussed in chapter 3. Although none of those selected was wholly owned by a multinational, one DBF had given up a controlling interest to a multinational after a period of independent status.

I carried out preliminary interviews in 14 small companies, out of which I selected six for more detailed analysis. Criteria used to select small firms for more in-depth study included the type of technology and sector orientation of the company to cover companies working with diverse elements of biotechnology in different parts of the food and agricultural sectors. However, a number of companies which had originally intended to work on agricultural applications had changed their focus to some extent after finding that opportunities were very limited in this area. As this was an important aspect of our research I included a number of these companies. In two cases, I was keen to do follow up work, but was denied further access by companies. In one case this was primarily due to time constraints on managers and an unwillingness to reveal details of their activities. In the other case, financial difficulties made managers unwilling to discuss current issues facing the company.

Later in the study, I included a Belgian company which is widely acknowledged as one of the leading new agricultural biotechnology companies in Europe. It seemed important, in light of the rather difficult situation of many British companies, to examine a seeming "success" story. This was valuable in terms of learning about strategic options for DBFs in the sector. Additionally, I included a US company which had significant links with one of the MNCs I was working with. The MNC had spent a long time investigating links with small companies before deciding on this particular DBF. From what I had learnt, the DBF appeared strategically important to the MNC and therefore I included the company in order to learn more about the MNC involved and their perception of a "well managed" DBF.

The following list provides details of the companies and gives the number of interviews which we had in each DBF.

DBF 1. (3 interviews) I interviewed the chairman, managing director and commercial director. DBF 1 mass produces cattle embryos and is developing transgenic animals for the pharmaceutical industry.

DBF 2. (3 interviews) I interviewed the chairman, the R&D manager and a project manager. DBF 2 is divided into three divisions which reflect the company's interests in plant breeding, using biological agents for use in crop production and technology transfer. DBF 2 had rights to certain areas of AFRC research; it had an arrangement with the AFRC which was similar to Celltech's one-time agreement with the MRC. This agreement no longer applies.

DBF 3. (2 interviews) I interviewed two senior managers in the agricultural division. DBF 3 has two divisions, one concerned with waste treatment and clean up

and the other concerned with developing biotechnology for agricultural and horticultural applications.

DBF 4. (4 interviews) I interviewed the chief executive, the technical director, the financial director and a product manager. DBF 4 works in the areas of cryopreservation and algal fermentation.

DBF 5. (5 interviews) I interviewed the Technical Director, the Executive Director, the Commercial Director, the Manager of the Fermentation and Genetics Department and a Research Scientist. DBF 5 started life with the intention of doing 50% of its work in the area of pharmaceuticals and 50% of its work in the agricultural and food sectors, but has shifted its focus increasingly toward the pharmaceutical sector.

DBF 6. (1 interview) I interviewed the Communications Director and was given printed material about the company's history and product range. DBF 6 is a Belgian company, based in Ghent. The company works in the area of plant biotechnology and has recently started a subsidiary which will use similar techniques in the area of pharmaceuticals.

DBF 7. (5 interviews) I interviewed the CEO, the financial manager, the technical director, the production manager and a product manager. DBF 7 is involved in horticulture and uses tissue culture techniques.

DBF 8. (1 interview) I interviewed the CEO. This company works with enzymes and develops applications mainly for the food industry. During 1990, it was acquired by a MNC who later sold the company. I would have liked to carry out other interviews in this company but was denied further access because of confidentiality and time considerations.

DBF 9. (1 interview) I interviewed the CEO. DBF 9 is one of the largest DBFs in Britain and enjoyed exclusive rights to develop MRC research. I decided not to do follow up interviews in DBF 9 as the company is exclusively producing for the pharmaceutical sector and has been the subject of other research projects which generated material which I could include in this project.

DBF 10. (1 interview) I interviewed the CEO. While this company had been involved in research into advanced biotechnological techniques, management decided that opportunities for profitable application in plant breeding were very limited and were very wary of spending large amounts of money on projects which would not prove commercially successful. The company had decided to concentrate on conventional breeding techniques. I was keen to do follow up work in this company. Unfortunately the company ran into severe financial problems which led to a certain amount of turmoil and changes in management and the company decided not to allow us further access.

DBF 11. (1 interview) I interviewed the managing director. This company works mainly with enzymes and products include Accelase (an enzyme cheese ripening system) and Savorase (an enzyme flavor producing system). The company was taken over by an Australian multinational and therefore I decided not to do more in-depth work.

DBF 12. (1 interview) I interviewed the executive director. I decided not to follow up on this company as it had always been almost exclusively devoted to work in the pharmaceutical sector.

DBF 13. (2 interviews) I interviewed the Director of Operations & R&D and the Director of Business Development. This company works in the area of cell culture, industrial enzymology, biopolymers and plant

molecular biology. The company was taken over by a MNC while we were carrying out the research.

DBF 14. (1 interview) I interviewed the vice-president. DBF 14 is a US company developing biopesticides which will replace chemical based pesticides. In the case of large companies I used a range of published data and Prof.Tait's previous research to identify three British based MNCs with significant interests in agriculture and food related biotechnology. I later decided to interview in two other companies, 1 French and 1 US both of which have headquarters and research activity in Britain. I made this decision on the basis of information gathered during the study which led me to believe that these companies were important 'players' in biotechnology innovation and would complement the study.

The following MNCs were selected (detailed descriptions of the companies are given in Chapter 4):

MNC 1 (5 interviews) is a North American based MNC, which has invested heavily in biotechnology. More than any other MNC examined this company had restructured its business on the basis of the new technology. It is involved in agricultural, plant and animal biotechnology. I interviewed the Head of Scientific Affairs based in Brussels, the Science Policy Manager based in St. Louis, USA and also from St. Louis, the Director of Biotechnology R&D, and the Public Relations Manager. Also I interviewed an R&D manager based in the UK.

MNC 2, (6 interviews) is a leading agro-chemical firm which had invested heavily in biotechnology and opened a new seeds division largely on the basis of new opportunities offered by the technology and in the hope that it would yield new higher value products. It is involved in a wide area of food, plant and agricultural biotechnology. I interviewed the Public Relations Officer

from the Seeds Division, the Seeds Division's R&D manager, the Research Director of the Seeds Division, the Human Resources and Regulatory Affairs Manager from Biological Products, a Senior Manager from Biological Products, and a Research and Planning Manager from Biological Products.

MNC 3 (4 interviews) has significant agro-chemical interests, although its core business is oil. At the time I began the study MNC 3 owned a major plant breeding company and seemed set to enter the new era of biotechnology. Over the course of the two years, company strategy changed and the company cut back on its commitment to agriculture - related biotechnology, targeting its work much more narrowly. I interviewed two senior managers at the company headquarters, an R&D manager at the Seeds company which was at the time of interviewing owned by MNC 3, but has now been sold.

MNC 4 (8 interviews) has interest in using biotechnology in food production and processing and therefore acquired a formerly government owned of plant breeding institute. I interviewed a senior manager from the Agri business division, two economists from the research and economic assessment department, a senior manager from the central research laboratories, the research director from the company's seeds business and also a research manager and the business manager from the same division.

MNC 5 (4 interviews) is a French based company and a major European player in agro-chemicals and has over the last few years made major acquisitions of seed companies in the hope of being able to include biotechnology in future R&D. I interviewed two R&D managers and a Biotechnology Research Director based at a research station in the UK and a Senior Manager from the Agrochemicals division in Lyon.

2.4. CONCLUSION.

This chapter has discussed a number of aspects of methodology and provided details of interviewing structure and the companies involved in the survey. Methodological and theoretical perspectives are not separate issues and hopefully this chapter has shown how aspects of methodology reflect theoretical underpinnings.

This study is unashamedly interdisciplinary. The factors influencing decision making about biotechnology do not fit neatly into one discipline, indeed the conclusions of the thesis explicitly make the point that trying to understand the process of innovation requires a multidisciplinary perspective. A criticism of multidisciplinary approaches is that they sacrifice depth for breadth or rigor for range. While this is obviously a danger, it is also possible to foster rigor at the expense of relevance. Disciplines can contribute to increasingly 'bounded rationalities' which while internally consistent do not have much to with the complexity which characterizes our world. Gareth Morgan advocates trying to "...foster a kind of critical thinking that encourages us to understand and grasp the multiple meanings of situations and to confront and manage contradiction and paradox, rather than to pretend that they do not exist" (Morgan,1986:33). This study tries to foster that perspective. It takes, on the one hand, a broad look at biotechnology innovation in context and looks, on the other hand, at the process from the narrower perspective of firms and individuals in them.

CHAPTER 3. DEDICATED BIOTECHNOLOGY FIRMS.

This chapter describes and analyzes some of the difficulties experienced by Dedicated Biotechnology Firms (DBFs). According to a variety of different perspectives, DBFs had appeared to be viable institutions for the transfer of science to the marketplace. Chapter 1 discussed how theories of Post Fordism, Kondratieff waves and Schumpetarian entrepreneurs provided the basis for much of this enthusiasm about small biotechnology firms. The chapter, however, also detailed misgivings about the linear innovation model and suggested that a number of socio-economic factors were important in determining the rate and direction of innovation and the success of DBFs. The findings presented in this chapter suggest that DBFs experience a great deal of difficulty in bridging the gap between excellence in science and creative ideas on the one hand, and successful profitable innovation on the other. The reasons for this relate both to the specific nature of biotechnology, contextual factors and more generalizable institutional problems confronting small firms. The results of the research reported in this chapter should be considered in conjunction with analysis presented in chapters 5 and 6; Chapter 5 examines in more detail the institutional and market factors which impact on biotechnology innovation and how this broader environment affects DBFs and MNCs. Chapter 6 provides analysis of the situation regarding risk regulation and patent legislation which further complicate the process of innovation.

3.1. DBFs and the Struggle for Survival.

During the eighties it became apparent that DBFs were in a very different position from their counterparts in the micro-electronics sector. In 1989, a prominent US venture capitalist commented, "This isn't Silicon Valley: there are major technical, regulatory, patent, and marketing risks. There is not a venture capitalist who has not lost money in biotech" (FT, 10 Oct, 1989).

In the early eighties in the US, analysts predicted two-thirds of existing DBFs would disappear in due course - through bankruptcy, merger or acquisition (Cape, 1984). In the late eighties in the UK, Oakey et al comment, "even this prognosis may be over-optimistic" (Oakey et al,1990:24)

When in 1990, Hoffman La Roche bought up the most successful new biotechnology firm, Genentech, The Economist concluded that 'The dream is dead'. Hobbelink notes:

> "The dream was about entrepreneurial success in biotechnology: university professors with sharp brains and commercial minds setting up small biotech companies that could grow into multimillion dollar empires. The parallel with the computer industry, where such companies as Apple, starting from scratch, are now challenging IBM and others, was often drawn. The dream was also about a highly diverse biotechnology sector with hundreds of independent small biotechnology companies competing shoulder to shoulder with large transnational corporations, thus guaranteeing a highly dynamic interaction responding to the real needs of the marketplace (Hobbelink,1991:31).

Small companies, it was assumed, could grow rapidly, competing with large companies on the basis of new technology. Additionally, the host of new opportunities would allow for new entrants over a long period of time.

However, biotechnology innovation took longer than many expected, money became scarce and large firms played an increasingly important role in developing the technology. Moreover, niche markets proved difficult to identify and small firms underwent drastic reorganization and culture shocks in trying to get their products to market.

Gerald Fairtlough, CEO at one of Britain's most successful DBFs, Celltech, during its early years, says that the company was built with three principles in mind:

> - to have enough financial resources to take a reasonably long term view;
> - to aim nevertheless for some early commercial success;
> - to achieve synergy between in-house scientific excellence and external scientific collaboration (Fairtlough,1989:157).

Celltech managed to become a profitable, independent company. Created under exceptional circumstance, however, it proved an the exception to the rule[7]. The government gave support and financial backing and most importantly, the company acquired exclusive rights to Medical Research Council (MRC) discoveries in key related fields. While most DBF managers would agree that the three principles constitute sound theory they found it extremely difficult and in many cases, impossible, to follow the Fairtlough formula.

This chapter focuses on DBFs and hopefully sheds some light on why small firms find biotechnology innovation such an up hill struggle. Section 2 discusses the nature of the problems confronting the firms. Section 3 looks in some detail at some strategies adopted by small biotechnology

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[7] As Dodgson points out in his detailed study of Celltech, it is by no means guaranteed that the company will remain independent (Dodgson: 1990).

firms. Section 4 briefly considers the implications of the study for conceptualizing the role which DBFs play in biotechnology innovation. Theoretical perspectives are further discussed in Chapter 7.

3.2. CONSTRAINTS TO GROWTH.

3.2.1. FINANCE AND FUNDING.

The lack of adequate finance to build up a product based business concerned all of the relevant managers I spoke with. The inability to finance activities with profits from the sale of products, is something which most high-tech firms experience initially, but is a particular problem in DBFs. One manager told us, "The ability to keep raising money is central to a business like ours. Research is invariably more expensive than you believe it will be and it takes longer." Another manager commented that biotechnology companies have very high 'burn rates', meaning that significant amounts of money get spent on projects which fail either technically or commercially.

Venture capitalists, who had targeted biotechnology at the beginning of the eighties, now shied away. "The business environment has changed significantly, venture capitalists are looking for established areas," one manager said. Biotechnology became viewed as high risk activity. DBFs aimed to produce radically new products. This, while potentially very profitable, made it very difficult to judge accurately in quantifiable terms, market potential. The 'newness factor' the same manager said, both repelled and attracted investors. Managers said that whereas the label 'biotechnology companies' had brought in money during the early eighties, it was increasingly a liability. When looking for money, in order not to scare investors away, some managers began to identify their

companies with the sectors they were supplying rather than their technological base.

In a number of cases, DBFs were able to get less capital intensive and less technically demanding products on the market rapidly. This, however, did not solve the funding problem. Even though these companies marketed lower value products successfully, they still had heavy R&D expenditures on further products. Very few could rely solely on profits to fund future developments[8]. Since the stock market crash of 1987, few DBFs have considered going public.

Regulations and uncertainty about patents distinguish biotechnology from other high technology small firms and add to the difficulties of getting high income generating products on the market quickly.

Managers in this survey often found that a difficult choice had to be made between diverting energy from the potentiality more lucrative area of product manufacture into contract R&D work offering short term survival funds, "but not providing sufficient profit margins" to promote further growth.

Even when obtained, venture capital proved problematic in a number of cases. One senior manager, when asked how he would do things differently if he found himself in a similar situation a second time, responded immediately that he would try and find longer term funding instead of relying on venture capital. In his experience venture capitalists, given what he perceived as their short term horizons, did not help the company to create the more exciting and profitable products; their primary concern was that the company break even or make a profit in the shorter

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[8] See Grieve Smith and Fleck, 1988 for further discussion of this point.

term. Additionally, UK venture capital companies pursue a 'hands off' approach to the firms they finance, providing very little in the way of management and decision making support. Managers in firms with longer term backing identified this as a positive feature.

The situation regarding venture capital funding of DBFs is very different in the US. First, more venture capital has been made available to DBFs (Orsenigo,1989). Additionally, more recently, the Japanese have been making significant contributions to venture funding of US start-ups. The Japanese both collaborate directly with DBFs and provide capital to "US start-ups through US venture capital companies" (Roberts and Mizouchi,1989:49). Second, US venture capital companies tend to be much more 'hands on' than British counterparts, providing companies with much needed managerial advice (The Economist, October 5, 1991).

Inadequate financing was identified as a major constraint by another recent study. Oakey et al surveyed 48 DBFs in Britain. 56% of DBF entrepreneurs in the study relied upon personal savings as the main means of funding the launch of their firm. 21% relied primarily on venture funding. In terms of continuing finance, 26% of firms relied primarily on self generated profits, (mainly from contract R&D rather than products), and 24% on venture capital (Oakey et al,1990:119). Interestingly, product-based firms were particularly dependent on venture funding. Oakey notes, "...in other recent work on high-technology small firms, ploughed-back profits were a far more prevalent main means of capital generation, with a 73% level of occurrence" (Oakey et al,1990:121). In turn the lack of finance inhibits product development. 21% of respondents in Oakey's survey stated that shortages of capital had directly inhibited them from introducing new innovations (Oakey et al,1990:125). This is a larger percentage than firms in other high-technology industries.

Oakey et al's study also provides interesting information about equity investment in DBFs (Table 3.1).

Table 3.1. PERCENTAGE OF EQUITY SOLD TO EXTERNAL BODIES.

% of Equity Sold.	Total.....	% of Total
0	17	(39.5)
1-50	9	(20.9)
51-100	10	(23.3)
Acquired	7	(16.3)
Total	43	(100.0)

(Taken from Oakey et al 1990:143)

When the researchers called firms back a year later, they found that 28% of firms rather than 16% had been acquired. An interesting feature of the table is the high proportion of firms which had sold over 50% of equity and yet still maintained some control by not selling controlling stakes in the company to any one party. Oakey et al consider this to be part of broader and planned strategy aimed at bringing in investment but retaining control. This accords with our findings. Most of the managers we interviewed were keen to maintain a level of independence and keeping a diverse base of investors was seen as one way of doing this.

Oakey et al (1990:145-8) also note that it was product-oriented firms who were more inclined to sell equity stakes and more likely to be fully acquired . On the basis of data which included information about acquisition deals, and acquisition offers or inquiries to smaller firms, they say, "...the initial external support and, in a number of cases, full acquisition, are likely to be prompted by the long-term potential contained in the product technology of new firms". While this data is not conclusive, it could be seen as signifying a no win

situation for DBFs; the further they move down stream and the more product oriented they become, the more likely they are to be acquired. On the one hand acquiring firms are more interested in product oriented firms and on the other hand, given the expense involved in product development, product oriented firms are the more likely to need external funding and may therefore view the option of being acquired in a friendlier light.

Finally, a number of the managers in this survey complained that UK government and EC support and initiatives were too difficult to obtain. The amount of managerial time that required to apply for funds deterred managers from pursuing this route.

3.2.2. THE SEARCH FOR NICHE MARKETS.

DBFs have enormous difficulty in identifying or creating niche markets. Oakey et al make the same observation. They relate the lack of accessible market niches to the slow development of a core technology. This is in contrast to the semiconductor industry where,

> "...the basic technology was invented at the birth of the industry, providing a basic core technology which small firms could acquire at a reasonable price and from which subsequent invention, innovation and diversifications could evolve" (Oakey et al,1990:152).[9]

My research confirms difficulties in market identification. However, these difficulties did not stem primarily from the absence of a core technology. Managers in our study indicated that difficulties associated with niche marketing had to do with non-technical factors, such

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[9] While Oakey et al do not specify what they mean by a basic or 'core' technology, they think it possible that a common technological base may emerge in the near furture which would unblock paths to innovation (Oakey et al,1990:152).

as managerial problems, lack of funding and finance, regulation, market and price structures. In a number of cases, small companies also had problems scaling up technologies, but this had more to do with specific product and design requisites rather than with lack of a core technology. For example, in two different cases, innovations which had worked well at the laboratory stage became problematic when they had to be incorporated in final product form and scaled up for manufacture. Here, the problem was not so much the lack of 'core technology' but lack of adequate knowledge and experience in final product design and manufacturing. Moreover, firms were often involved in more than one sector, which suggests that the lack of 'core' technology was not the problem. Technology often did provide a base from which to diversify. Nine of the firms visited were currently involved, or had previously been involved, in more than one sector. The others had taken strategic decisions, largely based on non-technical factors, to limit their efforts to one sector.

In general, managers tended to see that the lack of niche markets prevented further development of the technology rather than the other way round. Tait et al (1990) identified regulation as one of the principle blocks to niche marketing in agricultural and food sectors. Regulatory barriers give large firms an important advantage over smaller counterparts. However, while regulations acted as a barrier to entry for firms in our survey, they were not the only constraint or even the main one. In the areas of food and agriculture, regulation acts in conjunction with other barriers such as market and price structures, lack of finance and managerial expertise to prevent the firms from identifying or creating niche markets.

Agriculture related production is a relatively low value area, increasingly dominated by fewer and larger firms. DBFs find it difficult to create space in which to introduce new products. While both large and small firms find it difficult to identify areas which could give a higher enough return to recoup high R&D costs, large firms can compete on the basis of market share and economies of scale. They can also lobby for changes in the institutional environment which would make high value agriculture a possibility. This is discussed further in chapters 5 and 6.

There are additional reasons for DBF's difficulty in getting more radical innovations to market in the areas of plant biotechnology. In order to carry innovations through to the market stage, companies working with plant biotechnology needed to work with plant breeders. In order for new technology to work successfully, a high degree of skill is required in more traditional methods of plant breeding. Apart from the cost and complexity involved in acquiring a plant breeding operation, owning a plant breeding company meant DBFs were likely to be viewed as competitors by MNCs. The number of take overs of seed companies by MNCs in recent history means that there are fewer independent seed companies with which smaller companies can collaborate.

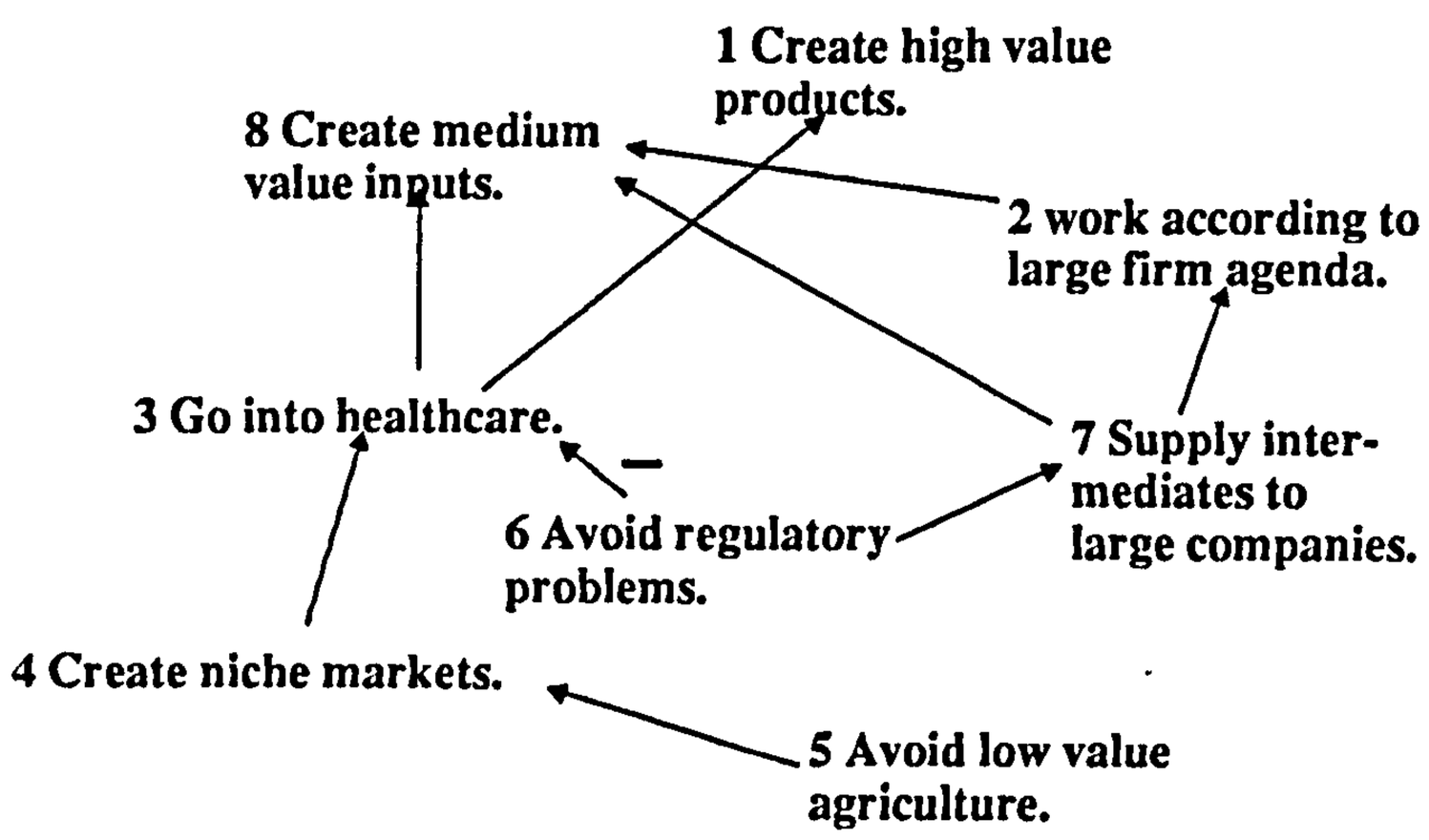
Given the difficulties of developing and selling higher value products, and the resistance to change amongst large companies, the majority of DBFs tend to lose sight of many of the more creative and alternative ideas which they had initially. For instance, one small company devoted a great deal of time and effort to working on insect resistance but had difficulty finding partners to develop the product; MNCs were not interested in products which undermined their chemically based agricultural products. The price structure of agricultural markets, the

fact that farmers would have to take initial risks and change habits and worries about patent protection compounded the problem. A manager from the firm explained the problems in the following way:

> "...if you put insect resistance in crops, you could use less pesticides...it turned out that no one was really interested in the early findings, like insect resistance. OK, you created insect resistant plants, but the pesticide industry isn't very keen on that - they might lose business. On the other hand, its only a benefit for the farmer not the seed industry. The seed industry has to persuade the farmer - might even have to give them free to the farmer in order to maintain market share. What happens in breeding, is that you come up with nice varieties, but you don't charge the farmer for your efforts. You come up with all this resistance and not be able to charge the farmer. If you could persuade the farmer that he or she would have to use less inputs, then you could charge more, but this is quite difficult...While there is an obvious benefit to the farmer, the seed company finds it more difficult to make money on this...And how do you protect all these things you put in plants?"

Additionally, a number of DBFs in our survey moved away from the agricultural sector because of the lack of accessible higher value low volume markets. The predominance of DBF activity in the healthcare sector has been noted elsewhere (Walsh,1988:20). Additionally, venture capitalists began to favor companies operating in the area of healthcare (FT,11 July 1991). While DBFs turned to the healthcare sector in response to these problems, there were also formidable constraints to developing niche products in this sector. In many cases, companies performed research services for large companies or produced non-regulated items, such as diagnostics, but could not gain access to higher value markets. Of the 14 companies we interviewed, 10 were involved either in product creation or contract R&D in the area of human health. All the companies except one which were active in the area of human health ended up producing the lower value

and highly competitive diagnostics, licensing out to multinationals or selling intermediates. Of these 10, only one had realistic chances of getting pharmaceuticals through to the final stage in the short term. The exception was Celltech which as previously noted is a 'special case'. Cope map 3.1. is based on a company in the survey and portrays the components of the decision to go into healthcare. The overall aim is to bring higher value products to market and this leads companies into the area of healthcare. In this way they avoid negative aspects associated with agricultural related biotechnology. But heavy regulatory costs associated with drug development mean that companies often end up supplying intermediates to large companies or carrying out contract R&D for those companies.



Cope Map 3.1.

Problems associated with lack of market niches in agricultural and food sectors are related to the production conditions in these sectors which are rooted in specific sets of social, institutional and economic factors. High value/low volume opportunities are few and large firms dominate the agricultural input sector.

3.2.3. REGULATION.

Firms found it difficult to deal with existing regulations in the area of pharmaceuticals and food products and managers worried that the specific regulatory regime governing biotechnology would prove prohibitive. The cost and complexity of regulations pose additional constraints in getting products to market. Additionally, while MNCs have experience in dealing with regulatory requirements, DBFs have to become instant experts. Often unable to devote scarce managerial staff time exclusively to regulatory problems, their difficulties multiply.

The EC finalized its regulatory code for biotechnology in 1991 but this has not put an end to the controversy surrounding the creation and implementation of biotechnology regulations. Many, although not all, managers in both large and small firms felt that the EC had regulated the technology, rather than the final product. This they considered 'discriminatory'.

Difficulties stemming from regulations contradict other policy efforts within Europe designed to promote small companies. However, more research is needed in order to try and assess the extent to which regulation, relative to other factors, creates problems for small firms.

It is tempting to identify regulations as the main constraint to small biotechnology firms. On the basis of information gathered during this project, however, it would appear that no one variable is the cause of small firms' problems; the situation is more akin to a complex web. Regulation constitutes only one part of the picture. Chapter 6 deals with the question of regulations in more depth and also explains how uncertain patent legislation has impacted on innovation in large and small firms.

3.2.4. COLLABORATIVE VENTURES AND CONTRACT R&D.

Collaborative ventures between firms have been an important feature of biotechnology innovation. In particular there has been a high degree of collaboration between large and small firms in the US (Hobbelink, 1991). The trend toward 'alliances' among firms is not limited to biotechnology, it is a feature of the development and commercialization of a number of high technology products and processes (Roberts and Mizouchi,1989).

DBFs showed both conformity and diversity in their approach to collaborative ventures. All the firms relied to some extent on external contacts with universities or research institutes for developing inputs and on other firms for developing and marketing final products.

As companies became more 'professional', and the focus narrowed, managers made drastic cuts in research budgets. Longer term research was cut down (drastically in some sections as the next section explains) and put out to universities or research institutes. Universities also worked on specific problems identified by scientists and managers which could not be dealt with in-house. These collaborations were considered in some cases to be successful and in others, not satisfactory in the main. There were some complaints that both universities and research institutes wasted time and money.

Licensing and joint venture agreements were often seen as the only ways, given the lack of experience and contact with distribution networks, in which they could get products to market stage. In terms of collaborations with large companies, a number of different perspectives and strategies emerged. Managers had diverse opinions about the pros and cons of licensing agreements, joint ventures and contract R&D.

Most companies pursued a strategy of both licensing and joint venturing, but the amount of licensing done varied considerably. A number of managers expressed a dislike of licensing agreements. They felt that by licensing the technology, they had lost control over further development and future markets. Some managers felt that a company should only license technology in areas that were not core to the firm and in which the firm had no development interest. Others saw the decision more in terms of short and long term aims. Some companies tried to combine licensing agreements with broader elements of strategy. One company, wanting to diversify its activities, was keen to attract large company R&D money on the basis that it would give exclusive licensing agreements once the project had been completed. Another company had made a strategic decision not to license technology. "We made a decision not to sell our technology, not to license. You have much more strength when you joint venture." This decision was part of a larger strategy which involved targeting technology development carefully. The same company also limited its joint ventures to international markets, developing and marketing its own products within North America where it was based.

Many managers felt that joint ventures constituted an acceptable way to take research further down stream. However, some managers noted the disadvantages of working with larger partners. One manager said that having had a bad experience where he felt the larger company "took the technology and gave little in return", he would prefer to steer the company away from this type of collaboration in the future. However, one manager said that it was particularly important to joint venture, rather than license when skills which could be useful to the company in the future could be built up. Another used joint ventures to gain access to global markets, while making sure that

they kept control of the home market, by doing local distribution and marketing themselves.

Undertaking contract R&D is a significant feature of many DBF strategies (Orsenigo,1989). Incentives to build up this feature of the production process come from two directions. For DBFs, contract research means short term cash. Sub-contracting out research and in some cases parts of the development process, has become attractive to some larger firms and is taken by some as evidence of broader shift to Post Fordist production techniques and horizontal forms of integration. However, contract R&D must be distinguished from more established and longer term collaboration. The latter form of collaboration was not widely evident in the survey of DBFs. Neither was it attractive to four out the five large companies interviewed in this study.

For most DBFs contract research represents a mixed blessing. On the one hand, it provides a means of short term funding; on the other it diverts time and energy from product development. The amount of contract R&D undertaken by the company depended on its ability or lack of ability to move further up stream into product development and it varied significantly among the firms surveyed. At one end of the scale, contract R&D was insignificant in one firm in terms of time allocation or income generated, and at the other end the scale one firm functioned predominantly on the basis of this type of collaboration. Most companies tried to limit the amount of contract R&D by time and the extent to which it fitted with other products. One company imposed a limit of 30% of its time spent on contract R&D. It also tried only to accept contracts which were synergistic with product development. Another company only took on modified R&D contracts which incorporated other potential collaborations such as joint ventures or licensing agreements.

It is interesting that none of the DBFs felt that there was a lack of opportunities to do contract R&D; the problem for small firms was knowing how to limit the amount of time and effort put into this type of collaboration. This is due to the fact that biotechnology is new and large firms have felt a deficit of knowledge and skill in the area. Therefore, for large firms, DBFs represented a convenient way of both getting specific work done and checking out the new terrain before making big commitments to building up internal resources. However, the high rate of acquisition demonstrates the precarious position of DBFs and the move towards vertical integration in larger firms.

There is considerable debate about the importance of collaborative agreements in contemporary capitalism. For some the increase in collaborative agreements constitutes another indication of fundamental change in capitalism; rather than the traditional pattern of periods of creative destruction followed by consolidation and increased vertical integration by larger firms, collaborative ventures signified new rules of competition (Best,1990). Pisano identifies some of the questions posed by collaborative ventures in the following way:

> "In the Schumpeterian model of "creative destruction", technological upheavals are characterized by protracted competition between new entrants and incumbents...The competitive dynamics of an industry undergoing a major technological change will be different, however, if new entrants and incumbents have and exploit mutually beneficial opportunities for collaboration. Rather than the new firms driving out the incumbents (or vice versa), the new and the old may co-exist in symbiotic supplier-buyer relationships" (Pisano,1990:2).

In a very interesting paper on collaborative agreements, Walsh outlines a number of reasons for increased technological collaboration in the form of "inter-firm co-operative alliances". In an increasingly

competitive environment, these agreements can be thought of by managers as good ways of:

1. sharing the costs and risks of R&D.
2. gaining access to new areas of technology.
3. gaining access to new markets.
4. gaining access to skills.

(Walsh,1991b:10)

In the case of biotechnology, both DBFs and large firms needed each other for these reasons. DBFs needed MNCs for all the listed reasons, but particularly 1,3 and 4. MNCs needed DBFs mostly for reasons 1,2 and 4. In an important and widely quoted paper Teece (1986) introduces the idea of "complementary assets." In the case of agriculture and food related biotechnology, the complementary assets which large firms process and which DBFs need are marketing and distribution systems, plant breeding facilities, the credibility needed to get farmers to change practices, the muscle to lobby for regulations conducive to innovation and the financial resources to be able to cope with long product lead times. Teece argues that in certain cases "profits from innovation may accrue to the owners of certain complementary assets rather than to the developers of intellectual property." This is particularly the case in areas where patents do not adequately protect innovation because products can easily be copied and 'invented round' (Teece 1986). The data from this study would suggest that DBF managers fear that MNCs will indeed be the ones to benefit most and that benefits of risk taking will be unevenly distributed in favor of the large firm.

Given the rate of acquisition of DBFs, the difficulties experienced by DBF managers and the increasing tendency by both DBFs and MNCs to try to increase levels of vertical integration, it also is legitimate to question the significance of collaborative agreements. High levels of vertical integration by large firms are often depicted as

representing a hierarchy rather than a pure market situation. The question then becomes whether collaborative agreements will act as an alternative to increased vertical integration and the subsequent building of hierarchies. Biotechnology is a new technology in which DBFs, being closer to the science base, often have an advantage in terms of knowledge about technology and skills. The amount of contract R&D and number of collaborative ventures between DBFs and MNCs indicates how important DBFs are to MNCs as a way of getting to know about the new technology and new areas. Given global trends toward increased sub-contracting (Best, 1990) and the range of skills and expertise which science-based DBFs offer, contract R&D may be a more enduring feature of biotechnology-based production.

However, it would be misleading to see contract R&D or collaborative ventures representing new forms of industrial structure in agricultural and food related biotechnology production in Britain. While some DBFs manage to negotiate better terms of collaboration than others (limited rights rather than exclusive, higher percentage of royalties or profits, etc.) they will find it increasingly hard to become successful product oriented companies via the collaboration route. First, this research has shown that many managers find contract R&D detracts from product development rather than aiding it. They also find collaborative ventures difficult and express worries about losing control of their 'seed corn' which could be used later to build their products. A number of managers felt at a disadvantage when trying to work with larger more powerful partners. This situation appears to be the product of a specific set of conditions. A recent study of collaborations between large Japanese firms and DBFs (mainly based in the US) portrayed a much more equal situation. US DBFs, with much higher levels of funding (itself increasingly a product of Japanese strategy as

mentioned) are in a much better position to negotiate on the basis of technological superiority. Roberts and Mizouchi say "Often neither firm appears to dominate" (Roberts and Mizouchi,1989:47). The Japanese are likely to pursue a two-pronged approach to biotechnology innovation, internalizing R&D and acquiring companies in some instances, but maintaining strategic alliances and collaborative ventures (Roberts and Mizouchi,1989). Thus they may well benefit in two ways. First, by collaborating with US DBFs, who have more resources, they are exposing themselves to leading edge technologies. They will benefit from collaborating with firms who have had resources to maintain an innovative and sharp small firm culture. In the cases where they choose to acquire, they will buy relatively mature operations which have had time and resources to accomplish high levels of innovation. Thus, the arrangement benefited both parties.

In Britain, the situation differs significantly. The uneven nature of collaborations, and the underfunding of DBFs mean that they become less productive, resorting to 'market led' options before they have been able to develop innovative technologies. The high rate of acquisition, particularly of product oriented DBFs, indicates that once MNCs have identified the direction in which they want to move, they will increase in-house R&D capacity. The findings of this study also indicate a preference amongst large British firms for acquisition rather than collaboration. These findings beg the question: what contribution can DBFs make to biotechnology innovation?

Oakey's opinion is as follows:

> "Put simply, a healthy and innovative small-firm sector is advantageous to large firms...There is a danger, as the industry grows that large firms will, through acquisition, stifle the emergence of a vital population of fast-growing small firms, from which they could purchase a diverse range of goods and services" (Oakey et al,1990:160).

The contribution of DBFs to innovation is discussed further in chapters 4, 5 and 7. Suffice to say here that Oakey et al's analysis of the trend toward rapid vertical integration in large firms in Britain appears accurate. As this happens life will become more, not less, difficult for remaining DBFs. There will likely be a further narrowing of market structure and the indications are that small firms may find it increasingly difficult to find space in which to grow. Moreover, as large firms gain more experience, they acquire powerful 'tacit knowledge' of technical aspects of development and of markets, regulatory and patent procedures which will give them additional advantages.

3.2.5. INTERNAL CONSTRAINTS, CONTRADICTIONS AND CHANGES IN CULTURE.

Lack of business experience amongst the 'start-up' scientists often made management of firms more problematic. In all the cases studied, additional managerial expertise was needed to deal with internal organizational problems, regulations, patents and collaborations with larger companies. In all of the firms significant changes in top management ensued after deficits in commercial knowledge became apparent. Often, investors insisted upon change. However, these changes created new problems.

The advantages which DBFs have over MNCs include the relative lack of bureaucracy and the high density of extremely well qualified employees. Ideally, DBFs constantly generate new ideas, are flexible and able to respond to new opportunities and learn quickly. Dodgson identifies small firm strength in their ability "...to diffuse learning throughout their organization quickly." Smaller firms in his view have fewer "organizational rigidities" (Dodgson,1991:118). In many cases, changes in management led to an almost exclusive preoccupation with

being 'market led'. This, combined with more formal bureaucratic controls, threatened this area of strength. One of the main dilemmas experienced by DBFs involved the inability to combine immediate production and maintain an innovative, experimental technological base. DBFs increasingly portrayed themselves as market driven companies with no interest in researching areas which had no immediate commercial relevance, with management changes reflecting this new priority. One manager described the process as one of "implanting a commercial gene into the company". In a number of cases, new top managers brought in to make companies more 'market led' had no previous experience either in the biotechnology or agriculture related business. One of these managers described his mission in the following way:

> "If you had come into the company a year ago, you would have found scientists. They weren't businessmen. Now you have people like me in - I'm a businessman with a bent for marketing. Virtually what I've done is write a marketing plan for the company. What we plan is not to be the first in technology, but to make money. Unashamedly because if we don't make money we won't survive. The company has changed totally during the last year. We are now market led. I've killed off projects which were very interesting scientifically but weren't able to generate cash."

The new concern with marketing and finding profitable outlets threw companies into "an identity crisis" in the words of one manager and provoked extreme changes in company culture. This kind of change puts DBFs in a very difficult, contradictory and dangerous situation. DBFs' capacity to innovate in technically difficult areas using high levels of expertise is key to their long term survival. Being the 'first in technology' and being able to diffuse technology quickly is the best basis on which DBFs can compete with large firms in the longer term. Short term dictates, however, often undermined this capacity; firms had to narrow the research base and put

resources into lower value products or contract R&D. Top scientists who had been attracted by the informal and exciting environment often left, disillusioned with the prospects for creative work. In some cases new managers positively welcomed this and were keen not to employ scientists who wanted to be too creative.

Given the background of many DBF founders perhaps it is not surprising that they needed extra business and managerial advice. A survey of UK DBFs established that 58% were founded by people with technical expertise, but no business experience (Walsh,1988:10). Additionally, the 'hands off' attitudes of many British venture capital firms meant that DBFs were rarely offered managerial advice from this quarter (Oakey et al,1990:158). In many cases, however, the process of reorganization threatened the very essence of the company; the company culture which gave DBFs a chance to compete with MNCs had to be abandoned in favor of cost cutting and short term security. Dodgson's study of Celltech provides important insights into the centrality of company culture to successful development. He says of the company,

> "The technology base in Celltech is the creation and the tool of its workforce. In the company the maxim that the strength of an organization lies in its people is particularly apparent. Very considerable managerial efforts have gone into fostering a well organized, committed and creative workforce" (Dodgson, 1990:86).

In another passage, he says,

"Science and technology provides the basis of Celltech's past, present and future competitiveness...the competitive position of DBFs like Celltech has depended first, on building up exceptional R&D skills based initially on academic links and second, on developing an integrated business capacity with distinctive advantages over large pharmaceutical firms based on their novel technological skills and organizational flexibility" (Dodgson,1990:52).

As in many other DBFs, one of the major problems afflicting Celltech was the likelihood that technological breakthroughs would not translate into successful products for at least another decade. The problem, however, will be multiplied if 'short termism' is pursued as a solution.

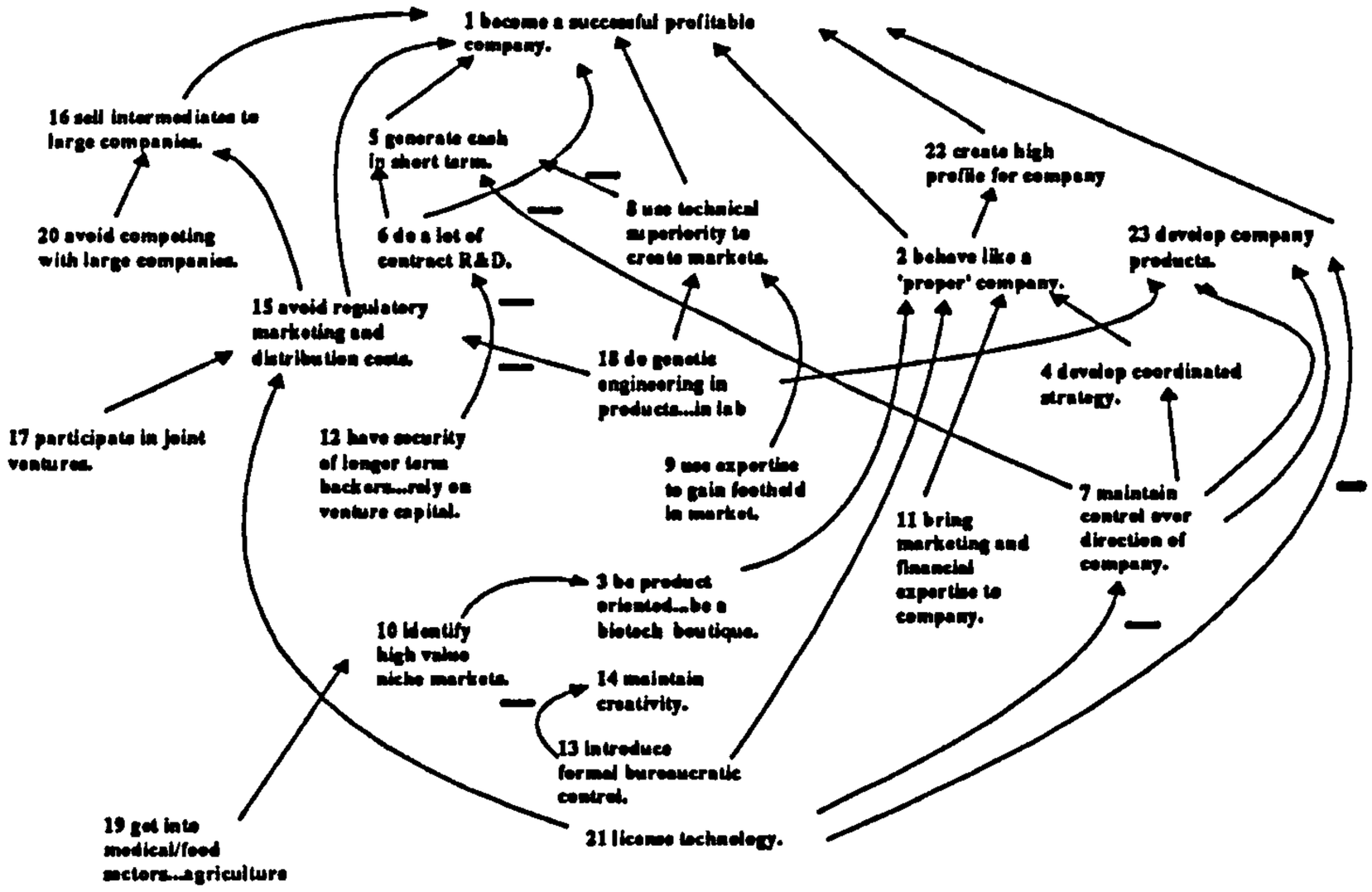
Another difficulty relating to conflicting roles which have to be played by the company emerged during the interviews. DBFs try to operate as 'biotechnology' companies, developing technology based products often with a number of sectors in mind and yet have to sell services and products into those established sectors. Managers to some extent found they fell victim to their own rhetoric. Biotechnology products have to feed into sectors such as agriculture or food, but managers, used to thinking of their company as a biotechnology company were often unprepared to deal with the specificities and complexities of different sectors. While DBFs acted on a cross-sectoral basis, developing pervasive technology, their customers, mainly in large companies, remained deeply entrenched within existing sectors. This led to numerous misunderstandings and made it difficult for DBFs to explain their mission. One manager from an ag-biotech company made the following comments.

"I think we have built companies for five years on the basis of technology and it has created a lot of problems, a lot of hassle...People ask, 'What do they want to do with it?' And they don't understand the problems. Like we say, we want to create added value - what the hell is added value? People have never understood what we were doing - for years people thought we were a tobacco company."

This added another pressure, along with the need to secure financing, for companies to identify themselves with established sectors, rather than thinking of themselves as biotechnology companies.

3.3. DBF STRATEGY.

Having examined some of the problems faced by small firms, I will now describe some of the strategies adopted by them. The first part of this section uses a cognitive map to portray different strategic options and their consequences. This is a convenient way of summarizing what has been said so far and connecting it to a fuller picture. It was possible to create a composite map (Cope Map 3.2.) of DBF strategies because the external constraints on their activities were so strong and so universal that they almost completely limited their freedom of movement, thus limiting the degree of diversity in DBFs.



Cope Map 3.2.

The top level goal of the companies was to establish a successful, profitable business, (concept 1). Feeding into this goal is a number of strategic options, several or all of which were part of the decision making strategies of the companies studied. The top, left-hand side of the map refers mainly to the companies' relations with external organizations while the bottom, right hand side of the map shows aspects of the internal organization and planning of the company.

The map shows that the external world was dominated by multinational companies, regulatory authorities and financial backers. Regulatory, marketing and distribution costs (concept 15) presented major hurdles for all the companies. Selling intermediates to large companies (concept 16) was one way of avoiding this. The latter also meant that the company avoided the risks of competing with MNCs (concept 20), who were also important customers.

In order to tackle regulatory, marketing and distribution costs DBF participated in joint ventures (concept 17), did genetic engineering in the laboratory

(concept 18) and then passed on the later stages of product development to MNCs to cope with, via contract R&D. Licensing technology was another means of avoiding regulatory, marketing and distribution costs (concept 21).

However, the latter strategy often provided a less than ideal solution; managers felt they lost control over the direction of the company (concept 7) and were unable to reap higher profit margins from final product development (concept 23). Joint ventures (concept 17) were also problematic for some companies; lacking the necessary muscle to negotiate "fair" agreements some small firms felt that large firms were getting access to sophisticated technology while which they appropriated to use in their own products at a later date.

The need to generate cash in the short term (concept 5) dominated much decision making. This was incompatible with the desire to maintain control over the direction of the company (concept 7) (negative sign on the arrow). The need for short term cash led firms to license technology (concept 21) and take on contract R&D (concept 6) which diverted energies from product based growth (concept 23).

In terms of internal management, creative anarchy, while exciting and productive in terms of generating new ideas, cost too much. They felt the need to begin to behave like 'proper' companies (concept 2) which means introducing formal bureaucratic controls (concept 13) which is not conducive (negative sign on the arrow) with maintaining creativity (concept 14). Behaving like a 'proper' company also involves developing marketing and financial expertise to the company (concept 11), becoming more product oriented (as opposed to being a 'biotech boutique') (concept 3) and hence identifying high value niche markets (concept 10), which were often seen as existing mainly in the medical and to a lesser extent in

the food sector (concept 19) rather than the agriculture area.

Using conceptual tools developed by Daly (1985) and Harrigan (1983), Orsenigo outlines four basic strategies which DBFs adopted to overcome some of the obstacles in their path. 1) Companies developed marketable products as soon as possible, gaining a lead in the market place through early specialization in a specific niche; 2) Companies built up core technological capabilities in a wide range of areas, "exploiting the technological synergies and complementarities made possible by genetic engineering and pursuing on these grounds diversification" (Orsenigo, 129:89). This strategy, Orsenigo notes invariably meant longer lead times and emphasized more "radical" innovations. 3) In terms of vertical integration, DBFs could try to establish early production and/or marketing facilities or 4) could rely on external partners, "subcontracting the manufacturing of their products and/or licensing the commercialization rights for different geographical areas to other companies or using existing distribution channels" (Orsenigo,1989:129).

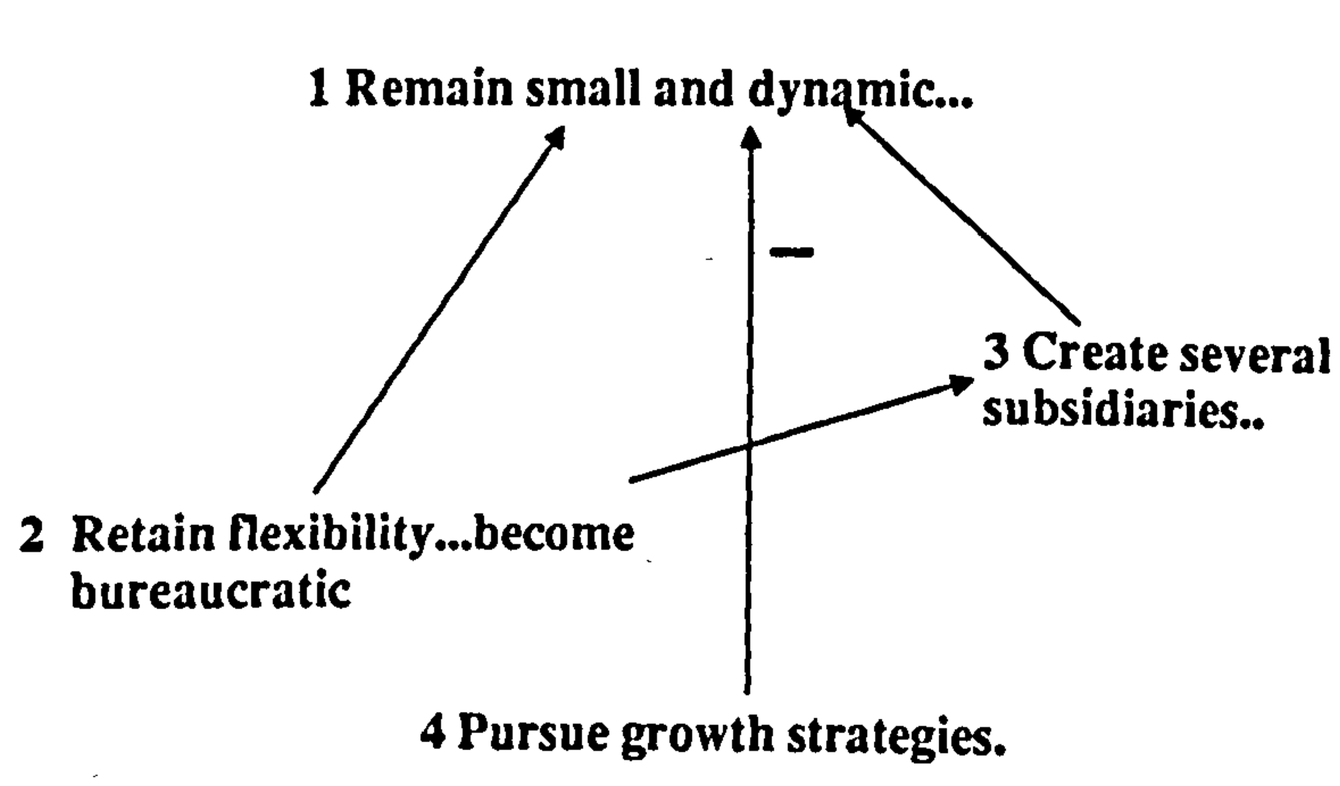
Orsenigo acknowledges that companies may adopt a combination of these strategies and indeed, in our study, we found that companies invariably tried to weave together different strategies in an attempt to keep their heads above water and were, in some instances, performing a rather precarious balancing act. To use the term strategy at all may be considered misleading in some of these cases. As discussed in chapter 2, strategic plans result both from rational, conscious choice and less rationalistic processes. The notion of strategy, however, does imply a future plan. In some DBFs there was very little strategic thinking in evidence; DBFs developed survival tactics, rather than planned strategies. They were reactive to

events, rather than proactive. In other cases, however, there clearly were planned changes in strategy.

One company, following a complete restructuring of operations and a change of top management, had abandoned many of the ideas and practices of being a DBF altogether. Using advanced tissue culture techniques, this company, had become as one manager put it a "contract supplier" of flowers and horticultural crops rather than a biotechnology firm. Development work consisted of identifying precisely the best technique for particular flowers and crops; there was no other research being carried out. The company had abandoned plans for diversifying into other areas on the basis of new technology. It became highly market led, working within a clearly defined existing business area. Its management culture became much more 'Taylorist', with a stricter separation between conception of strategy and execution of tasks. Improvement of existing techniques in order to cut costs while maintaining quality was the primary development concern. The company pursued strategy 1 in Orsenigo's classification and the nature of management problems changed over time from those associated with DBF toward more traditional mass manufacturing concerns.

Another company pursued a combination of Orsenigo's strategies 1 and 2. It aimed to create a 'cash cow' product which would fund more technically difficult and longer term projects. A number of technical problems slowed down development of the initial product. The company undertook a refinancing operation and found a number of new investors. The investors insisted that a top manager with significant commercial experience be appointed and wanted to diversify into other areas. The company is now at the stage where it can begin commercializing its initial product. It developed an agricultural product which had mass market potential and was able to take it through to the marketing stage independently. One manager

put this down to the absence of a MNC working in the area. Due to the limited opportunities in the area agriculture, however, it is moving, via a number of collaborative agreements into the area of health care. A senior level manager commented that a main worry now is how to balance demands from all investing partners in a way that will not damage the company in the longer run. There were several issues involved: the company had to avoid competing with its customers; it had to make sure that it was not becoming too dependent on one investor or customer and had to find a way to allow the venture capital companies to exit from the company. One possibility involved setting up a holding company and running a number of subsidiaries from the centre. One other company mentioned this idea. One manager considered it potentially advantageous in terms of company culture; companies could remain small and dynamic and yet pursue growth strategies. The components included in these strategic ideas are portrayed in Cope map 3.3.



Cope Map 3.3.

Two DBFs included in the survey were based outside of Britain. I included them because they showed signs of having negotiated various hurdles successfully. The first of these companies employed a mixture of strategies 1 and 3, and 4 and 1 in Orsenigo's classification; they specialized early and identified a bio-pesticide niche market which they pursued relentlessly. They concentrated on higher value speciality crops such as fruits and

vegetables, combining new techniques with existing technology. The company identified the area as one in which large companies would not initiate work. In the words of one manager: "When big companies develop products they develop for big markets. High value, low volume applications get ignored." Nevertheless the company has formed successful collaborations with large companies. Given the manager's view that the company initially innovated in areas of little interest to MNCs, this may well be considered as testimony to their achievements; the area has become too important for large companies to ignore.

The company identified international partners willing to foster the new technology. Significantly, one MNC partner is less committed to the conventional mix of plant breeding under the chemical umbrella than other large firms involved in agricultural inputs and thus perhaps was more open to new ideas. Another, committed to being at the forefront of biotechnology innovation, invested on the basis of the company's expertise.

The company limited collaboration both on the basis of quantity and quality; it develops and markets its own products in North America and only pursues collaborations in order to get access to international markets. Additionally, strategic considerations lead to a decision not to license technology; "We made a decision to sell our technology, not to license. You have much more strength when you joint venture."

The company formed in 1987 and was expected to break even during 1990 for the first time. Its top management came from MNCs and had considerable experience in relevant commercial areas. The company is based in the US and, as the senior manager I spoke with acknowledged, had much greater access to venture capital than most British companies. Thus external conditions have made life easier

for its managers and allowed them greater freedom to plan its course of action. One cannot compare companies' strategies without looking at the context in which they are operating, nevertheless the company's success is not only due to external financial conditions; it made important strategic decisions which gave it certain advantages.

The other company based outside of the UK is Belgium based. Up until recently, it has been active predominantly in the area of plant biotechnology. The company was started up in 1983 by a scientist with very close links to the University of Ghent. It was based on work which had been done at the university on genetic engineering. It was started with government and private money rather than venture capital. This gave it more time to build its scientific base. For the first two years, the company was almost entirely technology driven. In 1986, it underwent a complete change in management; a Harvard MBA took over as CEO and people with experience in MNCs took other top positions. Over a period, the company began to narrow down its activities and became more product oriented. During this period, it did lose its top scientists. But current management feel that the level of expertise in the company is quite high and that more fundamental work can be done in universities. While the culture of the company changed significantly, care was taken to allow scientists to keep publishing and pursuing activities as individuals rather than just company scientists.

The company's real success lay again in identifying a higher value technology which to develop. While it continues to work in such areas as protein improvement and insect resistance, it concentrated its efforts on creating hybrid plants. By creating sterile male hybrids, the company removed two major areas of uncertainty; the products will not need patent protection because they cannot self replicate and for the same reason will avoid

problems with risk regulation. Other areas of research were linked into this development. The management now identifies itself as being in the seeds business. In 1990, it brought in a top manager with 25 years experience in the world's largest seed company.

The company realized early on that because they were operating in a lower value area, they had to use their specialist knowledge and skills to create a product which would offer new opportunities to other companies as well as themselves. The creation of hybrid plants is such an innovation; it gives this company and others a way of protecting varieties and therefore, adding value to them.

The company has also been involved in the pharmaceutical area. For instance it has engineered plants to become production systems for high value pharmaceutical peptides. Additionally, on the basis of technology built up in the plant breeding area, a sister company has been formed which will innovate in the area of pharmaceutical products. The company, having built up its financial base and having already created saleable products, is hoping that it will have the resources to create final product drugs.

By expanding its investor base, the company secured 20 companies as shareholders. It gave priority to communications and PR and also to bringing legal and patent expertise in house. The company had 40 field trials in progress in 1990 and was doing work in both industrialized and industrializing countries. While they did not expect to earn a lot from work in developing countries, they saw it as good publicity and building markets for the future.

The company does not have any fixed rules about collaboration; it chooses the form of collaborations according to the crop and area of the world. Rather than acquire a large seeds company, however, it has generally

formed collaborative agreements and joint ventures with other companies to bring products to market.

At a more abstract level the differences between DBF typeas can be understood in terms of the conceptual categories introduced in chapter 1. Neo-Fordist firms, for example the first company mentioned in the strategy section of this chapter, become contract suppliers rather than leading edge technology firms. This leaves them vulnerable to other firms developing more efficient techniques or undercutting them in terms of costs. In the case of firms in the flexible specialization category, representing a number of companies considered in this chapter, difficulties stem from trying to balance demands of short term contracts with longer term product development. As with the second company mentioned in the strategy section, they are often involved in diverse areas and developing a coordinated strategy is highly problematic in these companies.

The third and fourth companies mentioned in the strategy section could be characterised as Post-Fordist producers. These firms have resolved a number of the problems confronting flexible specialization type firms through increased focus and productive collaborations with larger partners. It is perhaps significant that neither of these firsm are British and that even in global terms, the number of these firms in the area of agriculture and food related biotechnology appears to be small. The constraints have been detailed in this chapter, One particular problem is that Post Fordist strategy depends heavily on successful collaborations with larger firms. Yet, as the following chapter demonstrates, the majority of large firms in this study favored in-house development rather than extensive longer term collaborations with smaller firms.

Table 3.2. DBF TYPES

Neo-Fordist	Flexible Specialization	Post-Fordist
Contract supplier relationships with larger firms. Compete more on cost than with leading edge technology. Managed by generalists, perhaps with emphasis on marketing. Lower R&D expenditure, but firms lose their place at the leading edge of the technology and lose their competitive edge.	Biotechnology boutiques. Concentration on specialist high technology techniques. Managed largely by biotechnology experts. Difficulties in going beyond development of intermediate products. Problems in trying to balance short term contracts with longer term strategic work.	Focused approach to technology and product development. Strategically thought out collaboration with partners. Managed by ex-MNC managers with experience in relevant areas. Engaged in selective joint ventures, licensing agreements, to market products. Limited number of firms able to pursue this strategy.

3.4. CONCLUSION.

This chapter has raised a number of points. I have discussed the internal and external factors which influence decision making in DBFs, their implications and the connections between them. The study identified powerful external constraints on successful development and showed how external and internal constraints combine to push many DBF away from more ambitious innovations, particularly in the area of agriculture and food. Despite this, a few firms formulate strategies which do allow them to innovate

in higher value areas and maintain a level of independence. Key to these strategies is experienced management, the identification of 'core' technologies, selective targeting of product areas, carefully thought out collaborations with larger partners and avoidance of the more extreme versions of 'market led' strategies which lead to a running down of the company's assets. Time will tell whether or not these success stories will continue to prosper in the longer term. The fact still remains that the outlook for the majority of firms in this study, as independent entities, did not look bright.

The findings of this research are not conclusive; the study focused predominantly on companies in Britain and companies that were included from other countries were chosen because of their success. Thus, more international comparative work is needed in order to determine how much weight should be attributed to variables affecting these firms.

Further work should include the following set of questions: To what extent is the critique of the linear model outlined in chapter 1, relevant to the troubles afflicting DBFs? Or, on the other hand, are the problems being experienced not inherent to small high technology firms but rather due to national circumstance and industrial structures? Orsenigo, in his study stresses the importance of considering context when evaluating the role of DBFs; saying,

> "..The underdevelopment of [venture capital] and the smaller role played by Schumpetarian ventures in the patterns of innovation in science based technologies reflect other structural institutional and cultural features of the countries in questions" (Orsenigo,1989:151).

While a host of questions remain about the underlying causes of difficulties for DBFs, the findings of this chapter, combined with the study of innovation in large

firms, suggest some conclusions. First, although as chapter 1 explained, there seemed good reason to believe that DBFs might prove compatible with broader trends in the economy, the level of contribution they have made to innovation has been stunted by a range of interacting factors. In terms of the Post-Fordist framework, while industrially advanced economies are indeed characterized by an intensification of scientific exploitation and technological innovation, DBFs cannot, in the main, cope with the role they were thought to have had in transforming new science into marketable biotechnology. This is due to more circumstantial factors such as the lack of finance, difficulties in collaboration with larger firms, sector - specific problems associated with the agricultural and food industries and market structures. However, there are also more inherent difficulties relating to lack of resources and knowledge to ensure that firms can cope with technical and non-technical features of development, regulation and marketing. In particular, the spatial arrangement which separates DBFs from downstream processing, technical and commercial knowledge, hinders successful innovation. This is problematic because, as argued in chapter 1 and shown in chapter 4, the pattern of much innovation is not linear; it is an iterative process between different parts of the production process and is the result of learning by doing. On the other hand, while DBFs are likely to be unable to compete with larger counterparts on equal terms, larger firms, and the economy as a whole, may find it beneficial, as Oakey suggests, to have a healthy DBF sector. DBFs have advantages in terms of concentrated scientific excellence. Also, they are not hindered by previous experience and investment. For both these reasons they are likely to be quicker on their feet and more flexible than their larger counterparts.

In an interesting piece on 'market creation', Green (1991) identifies a number of 'institutional' and

regulatory problems which have created obstacles to the successful marketing of biotechnology based diagnostics. While Green deals with the area of healthcare, the study provides a useful framework for incorporating both detailed sectoral considerations and sociological and political concerns into innovation studies.

Monoclonal Antibodies (MAbs) opened up new possibilities for the identification of various ailments and conditions in humans. Diagnostics were attractive to DBFs because they offered a relatively short and cheap way to the market, partly because they did not involve time consuming and expensive regulations. MAbs could be used for quick and cheap diagnosis of a range of infectious diseases and promised, in addition to adding to cost reduction and efficiency in hospital laboratories, to open up a new market area offering an alternative to laboratory diagnostic services (Green, 1991:65).

The main markets were identified as being in US, where healthcare is costly and largely in the private sector. Unlike the UK, the cost of diagnostic testing is reimbursed by health insurance companies. Thus, one new market which was identified was the market for physician's office testing (POT) which by-passed hospital laboratories, offering physicians new sources of income. The second market was potentially even larger; if tests could be made simple enough, it was possible that they could be sold direct to consumers. This idea became known as over the counter (OTC) testing (Green,1991:68).

Green follows the fortunes of DBFs aiming to develop these markets and finds that most failed. They failed for various reasons; important complementary technologies which would have made self testing for sexually transmitted diseases easier, were not available; new regulations emerged after considerable controversy which required large firms resources; products which have sold well (such as

pregnancy tests) "incorporate principles appropriate to its manufacture, its final use by the 'consumer' and, something often forgotten, its retailing characteristics" (Green 1991:70). In the case of OTC tests products had to be professionally approved and "accompanied by good advice back-up including good labeling ('if in doubt see your doctor') and telephone advice points." Many doctors, Green notes, were not initially supportive of OTC pregnancy tests, arguing rather that all pregnant women need professional advice. Physicians' reluctance to relinquish control over pregnant women clashed to some extent with a culturally powerful feminist demand for more autonomous knowledge about the female body and more control over it. While OTC pregnancy tests have proved successful, it is large firms with the necessary resources to deal with marketing and distribution requirements and institutional requirements such as engaging in PR with doctors and fighting regulatory battles, who have been successful in developing end products. In the area of STD diagnostics, doctors have been extremely reluctant to encourage more autonomy and self diagnosis believing that patients need doctors' advice and counseling in dealing with their ailments. (Green,1991:70-73)

Green's analysis brings the social nature of market creation to the fore. He clearly identifies the need for institutional and social change to accompany technological change if new markets are to be created:

"The creation of new markets for MAb-based diagnostics has not fulfilled the expectations of early 1980s biotechnology enthusiasts. DBFs found it relatively easy to sell their MAbs, either built into their own kits or, more often, as components of kits made and sold by established immunodiagnostics firms to medical laboratories. MAbs were, in effect, just incremental (if important) innovations within immunodiagnostic markets. However, more radical applications of MAbs to STDs... proved more difficult. The market spaces for such tests required an engineering of institutional arrangements as well as appropriate technological developments. The study of the development of the pregnancy-test market, into which MAbs slotted in the mid-1980s, shows what institutional engineering was necessary. Innovating firms had to negotiate with regulatory agencies...and, on a continuing basis, had to convince and placate professional medical practitioners hostile to OTC testing." (Green, 1991:73)

Chapters 5 and 6 give further consideration to these sorts of factors in terms of agriculture - related biotechnology.

This chapter has raised important questions about the role of small firms in biotechnology innovation. They are confronted with multiple problems including, regulations, difficult collaborations, the nature of markets, market structure, patents, lack of management expertise, finance and funding. Nevertheless, it has been suggested that DBFs, in conjunction with large firms, may yet have a role to play in biotechnology innovation. Clearly, however, the findings presented in this chapter dispel two myths: first, that global trends are moving in favor of the small, innovative, firm in all sectors; second, that DBFs fit automatically into a linear model of innovation whereby small, innovative, firms which are close to the science base, will necessarily succeed in bridging the gap between invention and innovation.

CHAPTER 4. LARGE COMPANIES AND BIOTECHNOLOGY: DIVERSITY AND DOUBT.

This chapter examines biotechnology strategy in five large MNCs. It describes how companies incorporate new technology into existing operations and structures and how they envision biotechnology contributing to existing business activity. The five companies' strategies are discussed in terms of five variables: R&D and market identification; Organizational structure; Collaborations; Regulations and Public Relations and Culture. The companies displayed significantly different strategies and a variety of approaches. COPE maps summarize each of the large firms' strategy and portray the extent of the difference clearly.

This chapter argues that large MNCs have more room for manoeuvre than DBFs. Nevertheless, some firms were much more prepared to take risks than others. The extent to which firms committed themselves to biotechnology depended largely on their previous activity and place in market and industry structures. Strategies also depended on related issues of different economic and political assessments and cultural attributes. Additionally, strategies depended on their perception of public opinion and regulation. Regulations, public opinion, and patent

legislation will be discussed in relation to firms' strategy. This chapter draws heavily on the empirical evidence gathered during the two years of field work; broader discussion of these issues and the political and social struggle which surround the introduction of new risk regulation and patent legislation appears in Chapter 6.

This chapter portrays the cumulative nature of innovation and discusses the concept of learning by doing in terms of firms' strategies. Strategy was complicated by the difficulties of adopting new technologies and knowledge and of breaking with the past. This chapter also examines the various ways in which firms sought to do this and analyses different collaborative strategies. Again, while the field work provides the focus for this chapter, chapter 5 discusses in broader terms issues of collaboration and organization of production, together with analysis of changes in market structure.

4.1. MNC 1. OVERVIEW.

MNC 1 is a large integrated chemical company, with a turnover of over $7 billion. The company restructured its entire business on the basis of new technology; it aims to build a biotechnology-based business with extensive R&D and production in plant and animal agriculture, pharmaceutical and food biotechnology based business. This investigation of the company focused on its agricultural activities and the analysis which follows relates to this part of the company.

Previously, in the area of agro-chemicals, MNC 1 had been characterized largely as only a two product company, albeit tremendously successful products. In 1984, the sale of the two products provided for more than 60% of profits. In 1987, the patent on one product ran out and 'copy cat' competitors threatened the supremacy of the second. The

company also produced a wide range of chemical based commodities, but had few higher value, specialized products, in its portfolio.

Beset by low profit margins, falling profits and increasing hostility toward the chemical industry, the company took drastic action during the 1970s and 80s (Nill,1988). It increased its stake in the pharmaceutical business and bought into the seeds business; biotechnology played a major role in influencing MNC 1's growth and acquisition strategies. A manager analyzed the decisions taken at the time in the following way:

> "[MNC 1] determined that its major corporate strengths lay in the ability to apply chemical technology to the life sciences, as evidence by its strong positions in plant herbicides, growth regulators, plant breeding and certain pharmaceuticals" (Nill,1988:29).

A senior manager, interviewed in this study said that the company needed to find a new technology in order to maintain its profitability. It identified biotechnology as a major new technology which could potentially generate high profit margins. The adoption of biotechnology also related to the 1970s oil shocks and the company's reconsideration about its dependence on petroleum based products.

> "Businesses that are driven by petroleum feedstocks were too risky to be in, or at least, if you were in them you needed to be in feet first and control the market, which we didn't do. We had a range of businesses, from speciality to pharmaceutical to commodities and we were at the time, also looking to get out of the commodity business."

The company undertook an extensive review largely based on Hax and Majluf's transformation theory, which tries to identify companies' strengths in terms of conditions in the external environments. The approach

focuses heavily on developing corporate thrusts. (Nill,1988) By mid-eighties, MNC 1 claimed it had

> "...virtually completed its transformation of [its] chemicals, fibres, and plastics businesses from heavy dominance by commodity petrochemicals to a higher performance, less cyclical mix" (Nill,1988:32).

4.1.1. R&D AND MARKET STRATEGY.

In 1984, the company completed a $150 million biotechnology laboratory in the US. The complex houses R&D which feeds mainly into animal and plant biotechnology-based products. At the US lab, 1200 people work in the area of plant biotechnology alone. 280 have Ph.Ds. Managers regard the company as a leading-edge innovator. This position will serve the company well in global terms, they believe. A senior manager predicted that growth in Europe would be 'technology driven' rather than 'market led' during the nineties, with new technologies provoking change in process, products and industrial sectors.

MNC 1 made decisions about which technologies to develop first based on two criteria: first, the company wanted to build on existing strengths; second, it wanted to introduce technologies which would play a key role in relevant sectors in the future. This second component of strategy has been dubbed 'technological economic surveillance'. While the company pursued each strand of strategy separately (continuing with chemical based developments and, on the other hand, diversifying into new product areas) it also tried to combine the two objectives. The decision to produce recombinant Bovine Somatotrophin (rBST), a growth hormone which can increase milk yield by up to 20%, is an example of the outcome of these two strands of strategic thought. MNC 1's interest in Somatotrophins and animal productivity enhancers dates back to the 1970s. A lot of work was done

> "...splitting up naturally occurring BST into fragments, looking at the activity and working out the activity versus the structure and it was found that you needed virtually the whole molecule to retain activity."

Because BST is a large protein, traditional methods of chemical synthesis are not possible and so the project was shelved until the advent of genetic engineering opened up new possibilities. The first patent on recombinant BST (rBST) was taken out by Genentech and MNC 1 moved quickly to acquire the rights to the new product[10]. MNC 1 also began in-house R&D on recombinant Porcine Somatotrophin (rPST) which will reduce the fat content of pork.

MNC 1's extensive work on genetically engineering herbicide resistance into plants is another instance of trying to combine the two elements of strategy; the company is trying both to build on accumulated expertise and break into new areas. Other R&D projects include insect and virus resistance.

The company pursues a global strategy, aiming to create markets in developing countries; Third World countries want to increase production and while the company would not produce solely for developing countries, it considers demand from this source. Indeed, in some cases, products have been easier to sell in developing countries and Eastern European than in industrialized counterparts because of 'friendlier' regulatory codes. Currently rBST has been approved in Czechoslovakia, South Africa, Namibia, Brazil, Mexico and the states of the ex-Soviet Union. One manager said that products might be given free to peasant farmers in the Third World in order to create tomorrow's markets. However, MNC 1 would make Third World exporters pay for the technology.

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10 At the time the company began work on rBST, milk quotas had not yet been introduced in Europe.

The company is not only working on 'appropriationist' strategies, (Goodman et al, 1987) but has also developed a sugar substitute which is produced from a genetically engineered bacterium producing phenylalamine, a raw material.

4.1.2. ORGANIZATIONAL STRUCTURE.

MNC 1, while organized as a set of separate companies, places a great deal of emphasis on corporate culture and co-operation between businesses. Basic R&D which feeds into all sectors is carried out at the US research centre and biotechnology is seen very much as uniting sectors and creating new opportunities. One manager considers it one of MNC 1's attributes that it has created a structure and culture which allow for the dissemination of biotechnology research between different parts of the company.

> "...[MNC 1] had the foresight to realize that basic biotech research would yield breakthroughs applicable to both human and animal health care and to agricultural products as well. While most biotech companies have concentrated solely on one area...[MNC 1] has structured an organization that can capitalize on all the breakthroughs that emerge from their basic biotechnological research. This enables the company to reap maximum benefit from its invested R&D expenditures" (Nill,1988:34).

In addition to its willingness to adapt organizational structure in response to new technologies, the company has set up new collaborative structures.

4.1.3. COLLABORATIONS.

Collaborative ventures play an important part in MNC 1's strategy for biotechnology innovation. In the early days of its restructuring, it set up a venture capital company. Later, it established a European counterpart in

order to extend its reach. This fitted in with the company's technological environment approach. MNC 1,

> "aggressively invested in a portfolio of small entrepreneurial companies focused on agribusiness, biotechnology, and life sciences, electronic chemicals, process control and instrumentation" (Chemical Week, 14 Dec, 1983, quoted in Nill,1988:29).

MNC 1's Director of Investor Relations emphasized that exposure to new technology, also pursued in collaboration with university, had higher priority than financial return (Nill,1988:29).

MNC 1 also pursues more specific joint ventures and licensing agreements with DBFs and other MNCs. Some collaborative ventures are seen to be vital in accessing new markets and lead to acquisitions and mergers.

MNC 1 maintains high levels of investment in universities. The company 'donated' $23.5 million to Washington University for biotech research and provides research grants to other universities for more specific work (Hobbelink,1991:39). Based primarily in the US, the company operates in a context where industry investment in universities has a long tradition.

4.1.4. REGULATIONS AND PUBLIC RELATIONS.

Regulatory problems have plagued MNC 1's efforts to market agriculture - related biotechnology products and were always raised by managers early in interviews as one of the companies main concerns. Regulatory wrangles over rBST, both in the US and in Europe have slowed commercialization of the product down considerably. MNC 1 claims no negative side effects result from use of rBST but controversy over its impact on human health and animal welfare continues. Small farmers did not welcome the product and saw it contributing to economies of scale and

favoring large farmers. MNC 1 says this is untrue and that in any case, socio economic impact should not included in regulatory assessments. A senior manager also disputes the widely accepted view that milk is in surplus in the EC. One manager said,

> "BST has not really had any regulatory problems, its had what I would call 'political problems'. And its nothing to do with biotechnology at all. It comes up against these perceived problems of over-production of milk and all the rest of it - whether the small farmer will be disadvantaged - which all tends to be tied in with the subsidy he's getting - the CAP [Common Agricultural Policy]. There's a large amount of misinformation around. There are no surpluses right now."

On the one hand he said he did not envisage the same level of controversy taking place over herbicide resistance, on the other hand he depicted the argument over regulations as a political battle, in which 'rich greens' were gaining ground. His perception of the 'greens' was interesting.

> "I have to say that green interests are a rich man's privilege, a rich man's ideology, if you like. And that's pretty true of most of the greens in the [European] parliament...Count this and Baron that from Germany."

MNC 1 managers saw the problem largely in terms of 'them' and 'us', although exact perceptions of 'them' varied. Three of the managers I spoke with argued that consideration of socio-economic impact in licensing technologies constituted a form of central planning. One commented, "Its like they had in Eastern Europe and you know what happened there".

MNC 1 plays a key role in trying to promote the technology amongst policy makers in the US and tries to persuade UK and EC policy makers to support the technology. Its former President claimed that biotechnology constituted "a world economic revolution" and urged US and UK

politicians to give biotechnology political support arguing that knowledge is the "raw material" of the future, for industrialized countries". One of his specific requests to US politicians was for 'commitment' to the technology, in particular, he wanted a Presidential blessing[11].

MNC 1 is at the forefront of lobbying against 'process' based regulations, arguing that genetic engineering poses no special risks and that only products of biotechnology should assessed. It lobbies for patent protection of genetically manipulated plants, saying that the rate of innovation will be slowed down if patents are not given.

The controversy generated by biotechnology, and particularly rBST, has forced the company to reconsider the way in which it promotes biotechnology. Voicing the new line, one manager said he could see no reason to try and win people over to biotechnology; most people did not know what it was and it was probably better left that way. PR about biotechnology should be targeted much more closely to key policy makers. Public campaigns prove to be counter productive.

4.1.5. CULTURE.

MNC 1 ranks high on growth orientation, scientific and technological achievement. Success in biotechnology innovation has been such a high priority that security of profits and costs orientation have been secondary goals. Its concern with developing the technology has also been greater than its desire to create 'excellent products' in the sense of popular products with immediate potential to generate significant profit.

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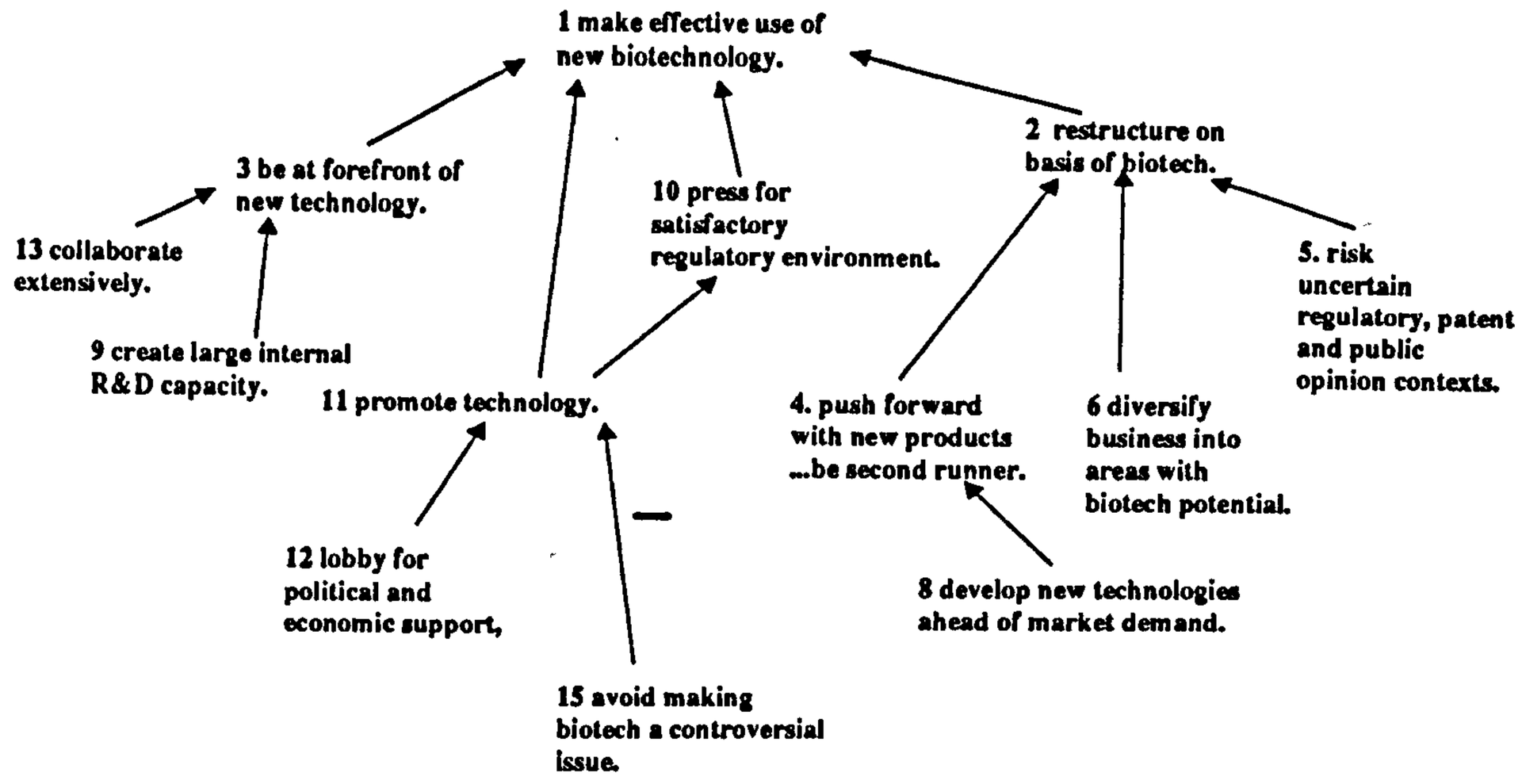
11 His request was granted with the formation of the Vice Presidential Council on Competitiveness, which has lobbied for business friendly regulations and provided funds for biotechnology development.

Indeed, the biotechnology thrust means that MNC 1 managers appear to have reified biotechnology to embody all that is good. MNC 1 underwent profound changes during the late seventies and early eighties and the organization's credibility hinges in many respects on the success of biotechnology-based innovation. The heavy identification with the technology has led the company into politically difficult terrain. Failures of, or problems with, particular innovations such as rBST, are viewed as resulting from the activities of political opponents, such as the 'Greens' or the 'Reds' who oppose the company itself, rather than as product related technical or marketing problems. While this may be accurate in some cases, constructing public relations around these arguments leads the company to take an adversarial, defensive stance when trying to promote its products. Other companies working with biotechnology voiced disquiet about the way in which MNC 1 handled public relations, believing that it was creating opposition rather than diffusing it. One manager from a another company commented that MNC 1's handling of BST was

> "...a very good case, in my view, of one company...thinking that they could go it alone with the general public, with the ministries, with everybody because the strength of their technical case was so terrific that nobody could challenge them...they were very naive to think they could just go on TV and just talk it out with a few people...having to establish real consumer need for biotechnology is an important element of the discussion."

MNC 1 showed relatively little awareness of consumer power. It is willing to defend products against a skeptical public. In this sense, it cannot be characterized as a consumer oriented company.

4.1.6. COPE SUMMARY.



Cope Map 4.1.

The COPE map portrays the priority given to technology by MNC 1 (concepts 2 and 3). It is both building a large internal capacity (concept 9) and collaborating extensively with external partners (concept 13). The company has decided to restructure on the basis of biotechnology (concept 2) even though the strategy poses various risks (concept 5). Its decision to push forward with new products (concept 4) means that it is developing new technologies ahead of the market, which also poses risks. The company promotes the technology (concepts 11 and 12) and presses for a satisfactory regulatory environment (concept 10). At the same time, managers have begun to realize that this strategy is unhelpful in that it makes biotechnology a controversial issue (negative arrow from concept 15 to concept 11).

4.1.7. CONCLUSION.

The following key points became apparent in this summary of MNC 1's approach to biotechnology innovation.

First, MNC 1 has staked much of its reputation and, indeed, resources on biotechnology and has tried to gain both political and economic support for its perceived mission as a forerunner of a technological revolution. Its commitment partly, at least, stems from its previous rather precarious hold on agricultural input markets; the company had relatively little to lose and a potentially a lot to gain by radically diversifying and building up a new core technology. The company identified biotechnology as one of the technologies which would be essential to industrial economies in the next century. The strategy has been to reorganize and diversify around the technology (technology driven rather than market led). It has spent large amounts of money buying up expertise and creating R&D facilities.

Second, while much of the company's innovation is cumulative in the sense that it builds on previous work, it has made serious efforts to break old patterns. Its wide network of rather loosely structured and longer term collaborations with universities and DBFs stands in contrast to other large companies studied. This type of collaboration perhaps better allows for the diffusion of more tacit knowledge. Additionally, its approach to DBFs, providing them with venture capital to build businesses allows for small teams to stay in place in those environments. In some respects, MNC 1 acts more like the Japanese companies mentioned in chapter 3.

Third, while MNC 1 has created fertile ground for innovation, it has had a multitude of problems in the areas of regulations and public opinion. The high profile given to biotechnology and MNC 1's rather ideological stance has to some extent backfired creating controversy over why and how certain aspects of biotechnology should be used. While the company has taken radical steps to change its structure and organization at the R&D and production end of operations, it has had serious problems with successfully

integrating marketing and public relations efforts with products. The constraints on innovation are clearly at this end of the production and marketing process.

4.2. MNC 2. OVERVIEW.

MNC 2 is a very large international full range chemical company, divided into highly autonomous businesses. Total group turnover amounted to more than £11.7 billion in 1988. Profits amounted to nearly £1.5 billion. I interviewed managers in the Seeds and BioBiz[12] businesses. MNC 2 has very significant interests in agro-chemicals; it is the third largest producer in the world. A major player in pharmaceuticals, more recently, as a direct response to opportunities made possible by new biotechnology, it invested heavily in Seeds. Over the past decade a strategic shift directed R&D more towards "'bio' fields of pharmaceuticals and, to a lesser extent, agrochemicals and seeds" (FT,June 20,1991). In addition to Seeds, MNC 2 created two other new business with the specific remit of exploiting biotechnology: Diagnostics and BioBiz. The overall MNC 2 R&D budget in 1990 was estimated to be at nearly £700 million. Bioscience accounts for 50% of R&D spending, and half of that is spent on agrochemical and pharmaceuticals, although, naturally a much smaller percentage is spent on third generation biotechnology. A senior manager summed up his vision for the company in the year 2000 in the following way,

> "First of all it will be a leading integrated chemical company. It will have by then a much larger pharmaceutical business than today with a solid presence in biotechnology, a continuing strong agrochemicals business and a successful, profitable and substantial seeds business" (FT,June 20,1991).

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12 This is not the company's real name.

4.2.1. R&D AND MARKET STRATEGY.

During the eighties, MNC 2 acquired a significant seeds business. To quote the Director of Seeds R&D,

> "[MNC 2] has made a major investment in that business. We've gone from a position of being nowhere in 1985 to now being the world's fifth largest seed company with a turnover of $250 million a year. Our investment in this business is because we believe that biotechnology is going radically to change the way that new plant varieties are produced in the future."

The seeds business uses a system of research targeting to guide much of its in-house work. The idea is to subject each research idea to a number of checks and to build up a body of knowledge about different markets. It is applied to short, medium and longer term objectives[13]. Each research project is evaluated quantitatively according to commercial value and technical feasibility. However, biotechnology, which represents potentially radical new developments, both in economic and technical terms, makes accurate quantification problematic. Thus, decision making tends to depend on "informed guesses." A primary objective of long term research is the acquisition of generic technology or understanding which can then be translated into more specific targets. In some cases, it resembles "an act of faith"; although it is impossible to identify exactly how the technology will be used, there is a faith that it will prove useful. The importance of these 'qualitative' judgements highlights the critical role of the tacit knowledge of experienced managers.

MNC 2 Seeds allocates about 10% of its R&D money to 'Skunk' work; scientists have time and resources to work on

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13 Although long term projects must be less target specific, managers aim riskier projects at targets with the highest potential value added.

their own 'pet' projects, without submitting ideas to any form of 'targeting'. About one skunk project a year becomes a commercialized product. One interviewee said that an environment where "you screw the resources so much down to the floorboards that everybody's delivering on time the dedicated target and doesn't have any flexibility" is not conducive to innovation. As a 'science-based' company, MNC 2 believes in the value of excellent science and creativity.

Biotechnology contributes in three principal ways to improving agricultural products: (i) improving the accuracy and selectivity involved in plant breeding and improving the 'genetic potential'; (ii) in "better husbandry" - work on fertilizers, pesticides etc. With regards to the first objective, primarily a process innovation, a lot of work concerns "characterizing and recognizing, in a very routine and useful way differences in the genetic make up of a plant." Together with other techniques, this, "makes the life of a plant breeder simpler - we can accelerate generation time..." Moreover, the process of plant breeding becomes much more selective. These techniques will not have an obvious impact in the market place, "...all that is happening is we're doing what the plant breeders always have done, but we're doing it much more effectively by giving him the tools of the trade. Probably half of our work is like that." A larger company with accumulated experience in traditional plant breeding and the seeds business will have enormous advantages over smaller companies in this sort of work. This is particularly the case if work in this area is to be combined with the second area of innovation mentioned; (iii) the introduction of new varieties (products) with genetically manipulated attributes. "The plant breeder cannot for example, introduce resistance to a particular disease if there is nowhere in that crop any resistance."

Managers stressed that simply inserting genes into plants is of no use, unless the plant itself is of good quality.

> "There's no point in having, say, a corn plant which is insect resistant, but otherwise useless. You've still got to yield a lot of high quality corn, its still got to stand up, its still got to resist a lot of diseases out there. In other words, its got to have all the other good agronomic attributes, plus this."

Traditional plant breeding still plays an important role and integration of traditional and new techniques is seen as key. Another manager described biotechnology as a 'knowledge revolution' and identified one of its main functions as adding to the total sum of knowledge about plants and agricultural inputs. He pointed out that even in cases where chemical applications continue to predominate, biotechnology will have contributed to better applications because increased knowledge will mean better technology, whether it be chemical or biological.

All managers made the point that biotechnology based products have to compete with existing products. In the context of relatively low value agriculture products and cheap chemical applications, this poses quite a challenge. One manager said,

> "Everybody gets excited about a new biological control agent, like Bt or son of Bt or something like that, but you've got to look again from the farmer's point of view or the foresters point of view. What has it got to offer that's better than what we've got now, and a lot of them don't stand up."

Thus, in a number of important managerial ways work with new biotechnology is likely to benefit considerably from previous knowledge and experience of plant breeding and the seeds business giving larger companies benefits over smaller counterparts.

Seeds pursues higher value applications, although the relatively low value nature of the market, dominated by very large sales of a few crops, prevents the high value/low volume objective from being an exclusive strategy. Thus, large acreage crops such as wheat, barley, sugar beet and oilseeds have been identified as primary targets for research and development. Seeds and agro-chemicals share R&D costs.

Other businesses also pursue higher value applications. At the beginning of the eighties one of MNC 2's highest profile investments in biotechnology was in a single cell protein foodstuff for animals. The development undoubtedly marked a technical achievement, but as oil prices went up (making alternative foodstuff relatively cheaper) the product became less commercially attractive. The inherent problem with fermentation technologies which involves draining off considerable amounts of water, proved capital intensive and expensive. A manager comments,

> "The experiment taught us much about how to grow micro-organisms on a large scale (1.6 million litres) but it also highlighted the inefficiency inherent in the fermentation process. More than anything else this focused our biotechnological attentions on higher value added products at the speciality end of the chemical business."

4.2.2. ORGANIZATIONAL STRUCTURE.

MNC 2 does not have centralized R&D facilities, but rather operates on a decentralized basis. The Bio-strategy group of managers, drawn from pharmaceuticals, crop protection and plant breeding tries to spread expertise throughout the company and coordinate efforts. MNC 2's decentralized R&D structure gives this group considerable importance. The group aims to ensure that the company benefits from what a senior manager calls 'corporateness', (FT, June 20,1991) ensuring that all the businesses can

make use of appropriate science when it arises[14]. The purpose of the decentralized structure is to give MNC 2 increased flexibility in determining R&D research programmes and provide added focus. Whether a team of top managers creates 'corporateness' and ensures diffusion of knowledge is an interesting question.

The tension between centralization and decentralization also poses problems for MNC 2 within businesses. One manager explained difficulties in combining new and old practices and dealing with geographical distance. The problem consisted of,

> "...managing the interface between old and new science...as a seeds company you have to do a lot of things locally. The routine - the classic process of plant breeding to produce new plant varieties and new hybrids - has to be done in the area where you are to produce plants that are locally adapted, and you can't do that anywhere except in the environment for which they are intended. Similarly, for a lot of crops, if you're successful in that the bulk of seed that you produce to sell is large and so the production, the processing, the bagging and selling also needs to be done rather locally. So that means that seed companies - even if you are a large company has to be composed of a lot of more-or-less independent units. There's a strong push to make it decentralized...So you have the basic science, the plant breeding - rather local. Now, when you look at biotech, you tend to have different requirements...you need critical masses of scientists and they have quite high capital requirements for a lot of expensive machinery and specialized laboratories...And its difficult, probably unaffordable to set these up in every breeding station..its a management dilemma."

In a sense, the problems result from a contradiction between localized and centralized knowledge and the

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14 The article in the Financial Times documents cases where the interchange of ideas between the pharmaceutical and agrochemcial parts of the company have resulted in significant product innovations, indicating that links between the businesses are productive (FT, June 20, 1991).

interaction between low-tech and high-tech activities. A related managerial issue concerns increasing the level of communication between different parts of the company. Basic R&D requires huge, and therefore centralized computing facilities. This creates a problem with disseminating results. One of the major constraints, cited by an R&D manager in MNC 2 was the difficulty of getting,

> "the IT [information technology] operating appropriately. You can't do this genetic mapping for example without being able to run large statistical programs and handle the results...getting that up to speed and then getting it accessible to the different scientists in different laboratories around the world is important. Getting different companies within MNC2 to communicate with each other is a priority."

A different set of constraints inspired MNC 2 to innovate organizationally; instead of creating links with DBFs, the company set up a 'mock' small company.

4.2.3. BIOBIZ.

Biobiz constitutes an extremely interesting attempt by a large multinational to reap perceived small firm benefits. After the failure of the single cell protein project, MNC 2 explored options; it wanted to create a space precisely so that, while working within defined parameters, the company would not be overly constrained by its past activities when trying to innovate with a new technology. The initial remit was

> "...to come up with new approaches in biotechnology that can be meshed into [MNC 2's] other activities - which range from commodity materials like plastics and fibres to pharmaceuticals and crop-protection compounds" (FT, 12 July,1989).

The founding Director developed a managerial ethos of a,

"...free-wheeling style of a kind more likely to be found in a small start-up company than within a large industrial combine like the 12bn-a-year turnover of [MNC 2]...We are very different from most of the other parts of [MNC 2]. We have little in terms of sales and all our energies are taken up in moving quickly and spotting new markets" (FT, 12 July, 1989).

In the early days, a priority involved picking up the pieces from the single cell protein project. Biobiz turned the technical achievement into a high value meat substitute aimed specifically at (according to marketing specialists) the younger, wealthier and female sector of the market. The founding Director said,

> "We are now careful not to overreach ourselves. Rather than concentrate on high volume projects with low profit margins, we are trying to look instead at making smaller quantities of materials with much higher value" (FT, 12 July,1989).

A biodegradable plastic, sold in Germany as packaging material for shampoo is another Biobiz innovation. Managers identified Germany as an appropriate market because of the strength of the Green movement and relatively high GNP which would support the high cost of the product.

One of BioBiz's objectives was to set up collaborations with outside businesses, including in some cases DBFs, in order to gain technical and marketing expertise. Managers in this company then had a positive view of collaboration and saw it as integral to their success. The company created a number of either wholly owned new businesses or collaborative ventures formed on the basis of common technology or common markets. A manager I talked with described the evolution of the business in the following way,

"For 6 years, [Biobiz] operated like a small company. We were treated differently. A wall was built around us...We've developed very much in the way that biotech has developed world-wide - from wide spectrum to major products. This is the strength of a large organization - product management. A certain amount of innovation, but product management is our strength."

BioBiz considered a large number of projects (there were 140 on the books at one point) but is now concentrating on six. The collaborative ventures with outside parties shared the risks of projects and brought in a number of skills. Managers stressed that not all the skills were technical, some being related to marketing or dealing with regulations in areas new to MNC 2. Thus, while Biobiz was similar to a DBF in some respects, it had far more resources and experience than are normally available to small companies. Moreover, its remit was to focus on the development end of R&D, rather than the research end. The wall built around the company was an organizational wall which allowed it to move in new directions rather than a wall which would have established Biobiz as an alternative research site. The aim of collaborations initiated by the company was to develop and market products in new areas rather than generate new research ideas.

4.2.4. COLLABORATIONS.

MNC 2 collaborates extensively with universities and research institutes, and participates in research programs sponsored by both the UK government and the EC. The company "sets great store" in working with universities and sees collaboration as essential to its operations. The company gives about 230 CASE awards (awards part funded by industry and government) and has over 30 collaborative ventures with universities. The model for collaboration is "where both sides will benefit". MNC 2, like all other

British based large companies in this study, stressed that universities should retain excellence in basic science rather than focus on development work and acts according to this belief. A manger commented "there's very little that we do where we just give a grant to an academic to deliver something in a contract sense." Rather, work will be on longer term collaborations of mutual interest. One of MNC 2's first big biotechnology products was the result of such a collaboration.

A manager from the Seeds business explained the company's reluctance to collaborate with DBFs. While MNC 2 buys technology from small companies, it finds that joint development agreements often prove problematic,

> "they want massive upfront money on things that are still risky. Their perception of risk and ours at the development end are very different...I understand why they do that as they are having some pressure from whatever their funding agencies are."

The manager acknowledged that DBFs were often quicker off the ground than MNCs, saying,

> "I think they were all faster off the ground in this technology than the big MNCs were. Time will tell whether or not the world changes as a result of the small company. You now begin to see a lot of the multinationals having their own programmes and buying up small companies and so on...."

MNC 2 is not attempting to create a 'new hierarchy' of the type mentioned in chapter 1, with DBFs pursuing various aspects of the R&D. However, the different elements of the company's strategy combine in such a way as to present the firm with new problems, some of which are similar to those confronting DBFs. MNC 2 is determined to be at the 'leading edge' of innovation and is unwilling to increase levels of vertical integration. One manager, commenting on a rival's decision to increase vertical integration, said,

"Fine, that's a particular business route they have chosen to follow. [MNC 2] has never chosen to follow that route. We've always chosen to keep ourselves as suppliers of fundamental discoveries if you like, I mean 90% of [MNC 2's] business is supplying things to other people to do things with."

With biotechnology, however, the company has found itself in the position of either needing to extend its vertical reach into many new areas or enter into agreements. MNC 2's work with tomatoes is a good example of this. A Seeds manager explains,

> "...What we have is probably a whole string of inventions...examples of lower volume/higher value type of approach... we already have a biodegradable plastic wrapping up shampoos in Germany...Probably the challenge then, is to set up the right sort of partnership...to bring this to the market. [In the case of tomatoes] we can collaborate with a plant breeder of tomatoes. Or maybe we set up a collaboration with a retail outfit or something in-between. Or maybe we go out and buy one...But if you go down the acquisition track people say, 'My God, do I want to get into this business of buying and selling thousands of tons of tomatoes on the Dutch auctions, simply to promote my new construct - its such a totally new, totally different sort of business...But that is actually the position of what you might call the small company with this genetic engineering...So bioscience, when you're looking at these small volume/high value-added components, it actually introduces some interesting challenges for effective collaborations and partnerships."

Thus, MNC 2 does not seek up stream collaborations with smaller companies. Down stream development and marketing agreements with other companies, however, will likely be sought. In the case of Biobiz, these agreements have already been established.

4.2.5. REGULATIONS AND PUBLIC RELATIONS.

Regulations and public opinion concern MNC 2 greatly. The company plays an important role in SAGB and has taken a relatively high profile in lobbying for favored regulatory options. Costs associated with regulations, policy decisions and different patent legislation are quantified and calculated in the research targeting process. While managers interviewed did not identify concrete instances where regulation influenced decisions, they pointed to capital flight from the EC biotechnology sector and to businesses which moved their biotechnology interests out of the community as evidence that EC regulations have a negative impact. Additionally, they threatened to move their biotechnology concerns out of the EC if regulations prove too severe.

One manager made a link between a 'bad' regulatory regime and patent environment in Europe and the targeting of biotechnology work on crops which grow in S.E. Asia and the US. He admitted, however, that SE Asia has, in any case, been identified by MNC 2 as a major new market area and that even discounting the regulations and patents as factors, the huge US market attracts investment. Thus, questions remained about the extent to which regulations, rather than positive market opportunities, influenced relocation decisions.

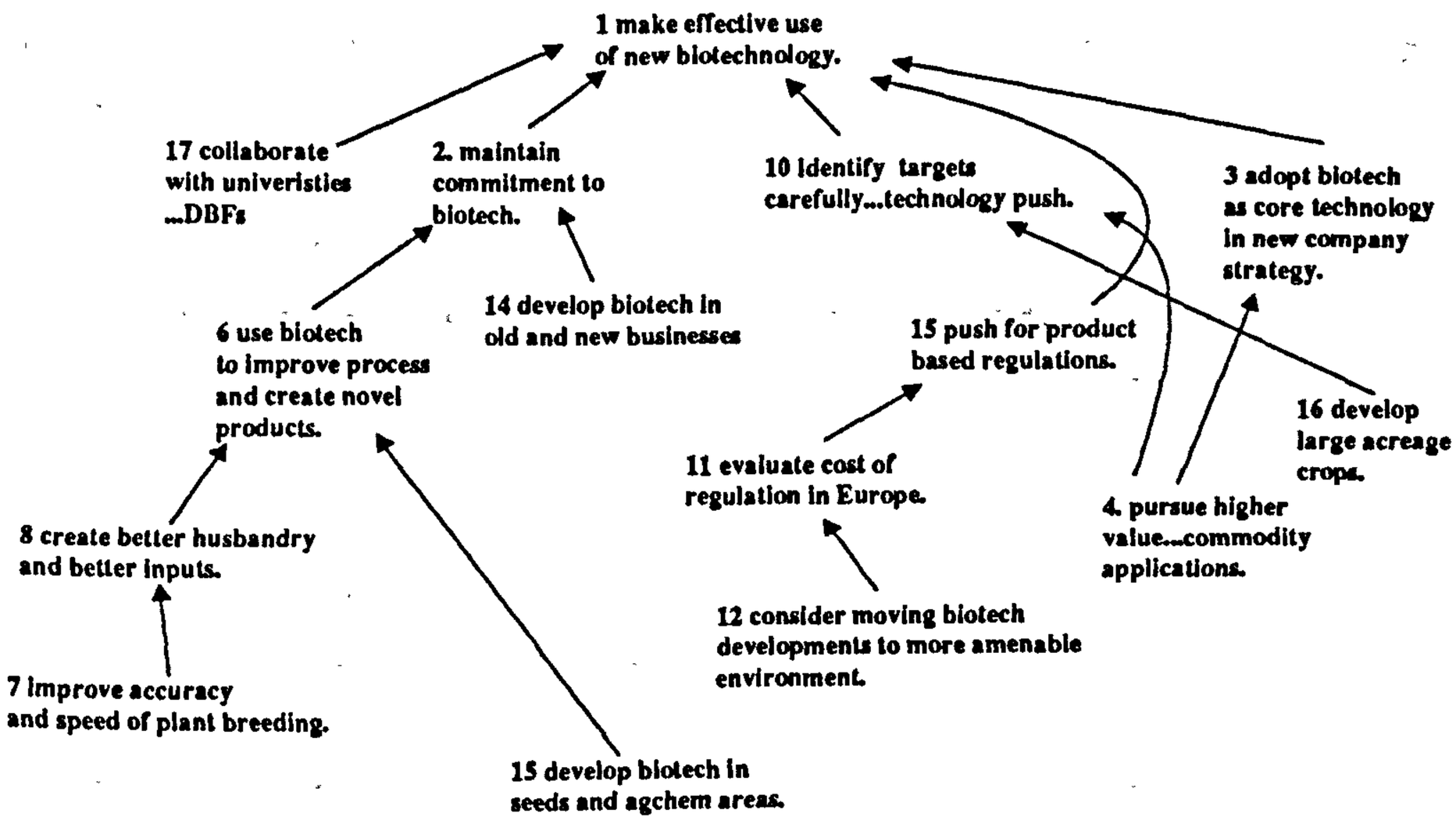
4.2.6. CULTURE.

Science, technology and innovation are integral to the company's identity. It likes to be seen as a problem solving company, with world class technological solutions. It jumped into biotechnology innovation enthusiastically while the market potential of the technology remained unclear. Growth orientation and scientific and technological excellence are high priorities. Concern with

security of profit, on the other hand, is not such an overwhelming concern that it prevents longer term work and ambitious technological projects.

MNC 2 retains flexibility in responding to problems presented by new technologies (the setting up of Biobiz for example) and innovates in cultural terms as well as in technological products and processes.

4.2.7. COPE MAP.



Cope Map 4.2.

MNC 2 has adopted biotechnology as a core technology (concept 3) for the future, but is identifying targets carefully (concepts 10, 4 and 16). It is using biotechnology in higher value applications and large acreage crops (concepts 4, 16) and to create both new products and processes (concepts 6, 8, 7, 15). The use of biotechnology in higher value applications ties in with a broader strategic thrust to move away from commodities (concept 3). Like MNC 1, it is attempting both to build on accumulated skills and knowledge, and use the technology to diversify into new areas of activity (concept 14). Unlike,

MNC 1, it does not collaborate with DBFs, but rather pursues collaboration with universities (concept 17). It is active in pushing for product based regulations and threatens to move its biotechnology developments elsewhere if suitable regulations are not created within the EC (concepts 15, 11, 12).

4.2.8. CONCLUSION.

A number of key points come of out of this brief summary. First, MNC 2 prides itself as an innovative company which maintains a high degree of scientific and technical excellence. As a chemical company it had to make fundamental decisions during the seventies about its future activities and whether it should focus on mass producing bulk chemicals or rather focus on its innovative abilities. While the company certainly continues to mass produce various commodities, it opted for the later choice in terms of strategic orientation. Additionally experience with single cell protein also encouraged the firm to target its innovation more carefully to higher value added applications. Second, in terms of biotechnology, the decision to be at the forefront has been costly; the company had to buy into the Seeds business at huge expense and suffered an expensive failure with single cell protein. Nevertheless, in a classic case of 'cumulative innovation' the failure led to development of another more commercially successful product. This example, together with the emphasis put on 'qualitative judgements, integration of 'old' and 'new' technology and facilitating communication also point to the importance of 'learning by doing' and tacit knowledge in the process. Third, internal reorganization has been a consequence of biotechnology innovation and, in Seeds, as we saw, internal organization and managerial problems persist. The problem of incorporating new biotechnologies persists. Fourth, the company has made some enormous shifts in direction in order

to incorporate biotechnology across a wide spectrum of activities. Yet it has retained its preference for decentralized R&D and its existing model of collaboration. Thus, its emphasis is very much on building up in-house R&D capabilities. While Biobiz represents an attempt to diversify down-stream activity, it does not collaborate with DBFs.

4.3. MNC 3. OVERVIEW.

MNC 3 was formed near the turn of the century and is a leading integrated oil company with extensive interests in chemicals, coal and metals. In 1988, the group had £55.82 billion turnover and £2.94 billion profit. It spent £428 million on R&D. During the 1970s, the company acquired 68 seed companies and formed one large seed firm which spanned a number of continents. The idea was to create a 'Green Revolution' synergy between high yielding varieties and agro-chemicals. However, MNC 3 represents a very different strategic approach to biotechnology. While this study was in progress the seed company was sold. The company did not develop the mix of chemical and biological based agricultural inputs characteristic of MNC's 1 and 2. It also sold its share of a joint venture set up with another MNC, which uses micro - organisms to produce industrial enzymes and fine chemicals. Additionally, the company sold its US agricultural research station and its US agro-chemicals business. After a period of searching, during which time the company reevaluated its position in markets and explored possibilities by acquiring and then selling DBFs, it defined its areas of interests much more narrowly. Now, the company focuses on developing a niche biopesticides market and a forestry mass market, in which it can play a leading role.

4.3.1. R&D AND MARKET STRATEGY.

During the early eighties, MNC 3 undertook a strategic review to see where biotechnology fitted into its operations. Three areas were identified as of potential interest, healthcare, biocatalysis and agriculture. Healthcare was eliminated as the company has no experience in pharmaceuticals and was too far down "the learning curve" to be competitive. Work on biocatalysis and agriculture were considered and central research continued to work in several related areas. Central research "has a contractor-customer relationship with the business sector...it also has its own budget...for general research." Initial biotechnology related work was done under the general research budget and businesses were then expected to pay for development. Problems became apparent when the Seeds business asked for further central funding to help with development.

The seed company proposed that more money be made available for research both within the company and at the company's central research laboratory. MNC 3 did not comply, preferring to sell the company instead. The decision provoked changes at the central research station; most biotechnology research concerned with crop biotechnology was phased out. The agrochemicals division now funds central research work, together with central funds. While work is being carried out in a number of areas, emphasis is placed on microbiology, plant molecular biology, biological control and forestry.

A senior research manager from central research pointed out various technical constraints related to lack of knowledge about ecology;

"...in terms of the high-tech biotech that's been done on fiddling around with genetics and things, its all come across the ecological problems that people didn't understand very well, so that there were super strains and they worked wonderfully in the laboratory but they were never very encouraging in the field."

Work on microbiology and plant molecular biology continues in central research and now focuses on soil structure and ecology. This could potentially contribute to the biopesticides and forestry work, although no specific targets were mentioned.

Some of the biological control work, such as the search for effective fungal pathogens, is, at the level of research, being looked at in horticultural plants. Because horticultural plants are often grown in controlled greenhouse environments, some of the ecological problems, which have constituted stumbling blocks to several biological control agents, can be avoided. It is also a convenient option given that the company has sold its plant breeding operation and has decided not to pursue crop development.

While MNC 3's involvement in agro-chemical and seeds markets has been significant, it accounts for a small proportion of overall company turnover. During the eighties, MNC 3 became less interested in committing large R&D expenditure to what was, for this oil giant, a low value business. Moreover, one senior manager indicated that the company had been slow off the mark in thinking about agricultural biotechnology and this created additional problems in terms of future development. He said that during the strategic review, with which he had been involved

"...it was interesting, quite worrying in fact, that people...felt it was going to be years and years...but in biotech, especially the ag side...its happened so fast. People were inclined to say since its so far away, why don't we just leave it, we can always go out and buy the know-how...Most of us in the planning department are inclined to say, no that's not very sensible'. The problem is if you go that way, you're quite likely to buy the wrong know-how. I mean if you're not in the game, you can't make sensible judgements."

Again the importance of cumulative experience and learning by doing becomes apparent. Reasons for MNC 3's withdrawal from the seeds business include: 1) Its main oil markets are high value and high volume and tend to overshadow other areas of operations; 2) Lack of commitment to developing and expanding the seeds business; 3) It was late in getting involved in agricultural biotechnology.

Concern about deforestation and alternative energy sources inspired MNC 3 to pursue forestry. MNC 3's operations in relevant parts of the world put them in a good position to dominate markets. Company culture, discussed below, also influenced this decision. Biological control was identified as an important area for several reasons: a) society's increasing hostility towards chemical inputs; b) development of resistance in insects to traditional chemicals; c) the inability of chemical solutions to solve certain disease problems in plants. d) the company's previous involvement in this area. In-house work on biologically based insect control agents is done in conjunction with DBF 6; MNC 3 cross screens DBF 6 strains against pests in its potential marketing area.

In MNC 3, scientists and business people make R&D decisions together, but the communication often begins with the R&D manager trying to sell ideas to management. The manager I talked with described himself as a 'middle-man' in this process. While much of the work done at the

central research station is commissioned by specific businesses, central funded research is as one manager said "real technology push". This is because centrally funded research is not considered "corporate research" but is less strategically planned than that term would indicate; central research seemed to be viewed very much as a font of ideas. While significant areas of fundamental work, are 'put out' to universities, much of the in-house research is not directly related to commercial needs or plans. Business and scientific objectives were viewed as distinct areas by the research manager interviewed and communication between people with different aims was not always easy.

> "I suppose at my level and the scientists that work for me, you try and, I think you have to, pick up the people who have a very strong commitment to certain areas of work. So, you have the scientific commitment here and the managerial commitment there...I guess a lot of my communication really is trying to sell my science to get somebody to give us the money. Its no different from being in a university."

The autonomy of central research was exemplified by the research manager's response to a question about MNC 3's change in strategy. He said that yes, he supposed the strategy changed, but apart from some reorganization and less work on crops, central research had not changed greatly.

4.3.2. ORGANIZATIONAL STRUCTURE.

This autonomy in central research permitted biotechnology work to continue even after the seeds company had been sold. If seeds had been more integrated into the company, more of the biotechnology research capacity would have been sold with the company. On the other hand, it is not clear where the existing research will be channeled. Additionally, perhaps if central and seed research operations had been more fully integrated, a more powerful innovative base could have been created.

The level of decentralization means that MNC 3 is characterized by an extremely complex organizational structure. Two main companies, one an oil company, Dutch in origin, the other a 'Transport' company, founded in Britain constitute the corporation. MNC 3 companies are active in six main Business Sectors, covering Oil and Gas, Chemicals, Metals and Coal. The main business is now conducted by operating companies, "of which there are several hundred in over 100 countries." Agricultural biotechnology falls within the agro-chemicals division of the chemicals business. Operating companies are expected to largely fund their own R&D. In the case of MNC 3's Seeds company this presented problems in undertaking expensive biotechnology R&D. Requests for R&D funds to be made available from central sources, as mentioned were turned down. While significant 'ground work' was done both in the seeds company and the central research facility, funds to link the two and build on this work were not provided. This seemed to be partly because of the company's tradition of 'arms length' dealings with operational companies and partly because the company did not see seeds and plant breeding as strategically important to corporate objectives. While the Green Revolution had inspired chemical companies to invest in seeds in the hope of higher profit margins, the seeds business remains relatively low value.

4.3.3. COLLABORATIONS.

MNC 3 collaborates extensively with universities. However, increasing amounts of fundamental work tended to be undertaken in-house,

"because the universities are no longer the repository of fundamental information that they used to be, so quite frankly there are things that I have to do in-house now that a number of years ago we would never have dreamt of doing because they were academic...I'm basically quite appalled at some of the research that isn't around."

MNC 3 became part of a government/industry funded project called PROSAMO to look primarily at the interactions between genetically manipulated organisms and ecosystems. MNCs 2 and 4 are also involved with the project. PROSAMO was undertaken mainly as a public relations exercise to reassure the public about the release of GMOs.

> "The whole objective of PROSAMO was to be very publicly visible because its entire raison d'etre is in fact to demystify areas of risk assessment and to act as an advocate of the technology and to demonstrate the presence or absence of risk, and to make that public."

MNC 3 conducted an extensive search for suitable DBFs with which to work. They eventually decided on a US based company which works on bio-control and, in particular, with genetically manipulated Bt. The various reasons for the decision to stay with biopesticides have been discussed. Another consideration which may relate to the fact that the particular DBF was chosen is that the Vice President is an ex-MNC 3 manager.

4.3.4. REGULATIONS AND PUBLIC RELATIONS.

MNC 3 has not yet run directly into regulatory hurdles and admits that it "is much more reactive in this respect than [MNC 1 and MNC 2]." The company will not individually promote biotechnology as a matter of policy, but it has joined industry organizations and played a leading role in setting up PROSAMO.

The company is not involved in SAGB. According to one manager this is because it has adverse reaction to getting "politically" involved with promoting technology. Another said that MNC 3 did not get involved in European initiatives and was therefore less interested in promoting biotechnology through this forum. Another said, it did not have a high enough stake in the technology to warrant that level of activity.

4.3.5. CULTURE.

MNC 3 worries about security of profits and whether future profits will generate significant profit margins. Given this, there is a somewhat contradictory attitude towards costs; levels of central R&D funded by companies are strictly limited to the amount that the individual company can spend and there is a strong belief that companies should be able to 'stand alone'. However, funding for basic 'untied' research is generous and the company showed awareness that short term objectives related to balancing books did not constitute adequate measures to insure longer term success.

This contradiction may relate to the fact that the company's main business is oil. On the one hand this makes it a rich company, which can afford significant central research facilities. On the other hand, it judges companies' performance by the standards of the oil business which can well afford to fund its own research.

Managers both in the former Seeds business and in MNC 3 commented that the two companies had significantly different cultures and that they had never truly meshed. Certainly, the seeds company's objectives did not seem to relate in any way to other parts of MNC 3's operations. The manager I spoke with was adamant that he would not work on herbicide resistance, one of the common vehicles for

combining biotechnology with existing chemical inputs (he thought it would prove unpopular with the public and that it was not the best use of the technology). Rather, the seed company was interested in developing biotechnology derived disease and insect resistance and using the new technology to speed up the process of plant breeding. One report on MNC 3's biotechnology strategy alleged that the seeds company research manager did not even know the names of MNC 3's herbicides (Biotechnology Development Monitor, No.7. 1991). In this sense the Seeds company could be described as embodying the attributes of 'scientific and technological excellence', product excellence, consumer orientation, while MNC 3 was more concerned with security of profits. The Seeds manager interviewed thought that the distance between parent company and subsidiary had some advantages as well as disadvantages; the Seeds company had been allowed to get on with its business without too much interference. But, biotechnology presented the company with a number of alternatives which went against the grain in various ways.

The MNC 3 research manager interviewed pointed out another level of culture clash provoked by the nature of biotechnology itself. To make the best use of the technology, he said, meant in many cases developing a portfolio of niche markets. This is because, as mentioned previously, biotechnology increases scope for specialization and flexibility.

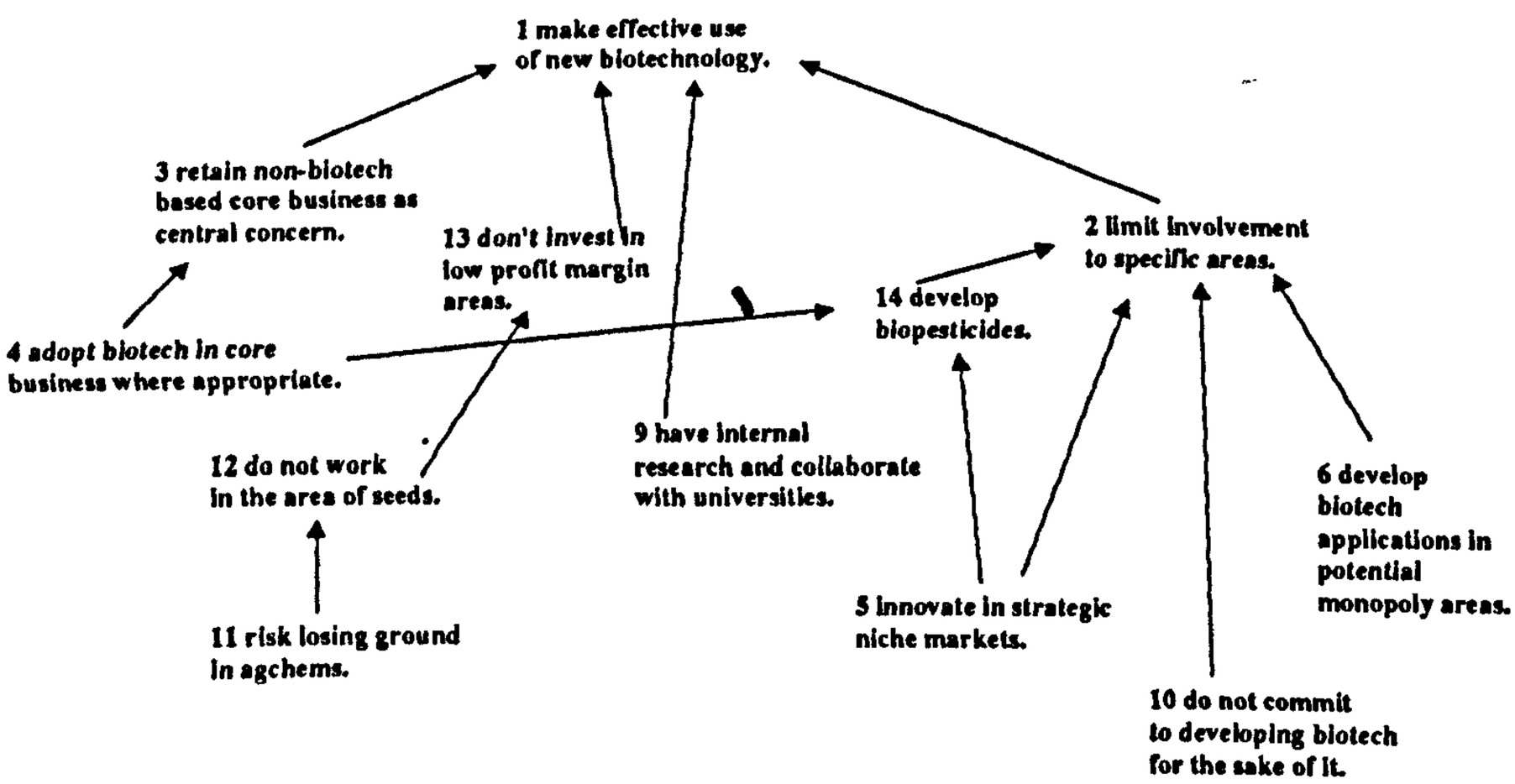
> "...When you talk about the strength of a biocontrol agent being its specificity...you have to have a portfolio of niche products, and you have to understand how to market that, and it is a different technique. Certainly [MNC 3] does have a kind of traditional philosophy if you're not talking about a million, to us then its a niche market."

The company pursued a niche market in biocontrol agents, but this could be an exception to the rule based on

the fact that the company had a tradition in this area of activity.

MNC 3, which often describes itself as an energy company, has found one area of plant biotechnology that fits with both its culture and organizational set up. Large scale forestry projects, begun in the early 1980s, gives the company both short term profits in the massive timber market and "If biomass becomes an attractive source of energy, [MNC 3] will have the necessary experience and infrastructure in place for a headstart in this field" (Biotechnology and Development Monitor, No.7,1991). Thus, this area 'fits' in terms of large markets and with respects to its potential application to energy generation, an area in which MNC 3 is a world market leader.

4.3.6. COPE MAP.



Cope Map 4.3.

The COPE map shows the difference between MNC 3 and companies discussed previously in this chapter. The company will retain non-biotech based business as its core activity (concept 3), but will use biotechnology in its core business, where appropriate. However, it is active in

developing biopesticides (concept 14). It is narrowly limiting its involvement with the technology, focusing on niche markets and areas where it may have a monopoly position (concepts 2, 6, 10, 5,). It has withdrawn from the area of seeds (concept 12) and because of this may lose its foothold in the agro-chemicals business (concept 11).

4.3.7. CONCLUSION.

Several important points about MNC 3's strategy emerge from this discussion. First, strategy is partially determined by the fact that few markets are as profitable as oil markets; the company therefore has less incentive to diversify into other areas. Second, and perhaps a related point, the company had grave doubts about the profitability of the seeds business. Being involved in seeds meant a heavy commitment to developing business in Europe and the US and the likely returns were judged too small to warrant the investment. The company felt that the profit margins in the seeds business did not allow it to foot the bill for expensive biotechnology R&D which would have been necessary to make it competitive in the long term. Third, in accordance with company overall policy, the R&D could only have been funded by transferring funds from another division of the company and this was considered inappropriate. The seeds company was never deemed a central concern and remained culturally very much on the outside of the main company. The very decentralized organization of the company meant that R&D done in central labs was never fully integrated with seeds research. Fourth, biotechnology strategy as it stands clearly builds on previous areas of interest and activity; innovation in this case is clearly cumulative in nature.

4.4. MNC 4. OVERVIEW.

MNC 4 is one of the world's largest food companies and the world's largest buyer and seller of oils and fats. In 1988 the company had sales of £1.7 billion and a profit of £1.5 billion. MNC 4 both diversified and strengthened 'core' business during the eighties. Non-core activity like transport, paper and packaging and petroleum based chemicals were disposed of. The following activities are now considered core business:

-edible fats and dairy
-food and beverages
-detergents and toilet preparations
-speciality chemicals
-agribusiness
-medical products. (Biotechnology and Development Monitor, No. 3:1990)

The medical products division was established during the eighties on the basis of new opportunities in diagnostics made possible by recent developments in biotechnology. It has already had considerable success with its pregnancy and ovulation diagnostic kits.

While MNC 4 still considers itself a marketing and consumer organization, it was forced to increase its R&D capabilities in order to remain competitive. During the eighties, MNC 4 sold and acquired companies frantically. In 1989 alone, the company took over 55 companies for a total sum of about US $ 3 billion. (Biotechnology and Development Monitor, No,3: 1990). Acquisitions increased the company's global reach and provided it with significant R&D capability. A desire to increase vertical integration and control the whole chain of production also lay behind a number of important acquisitions.

MNC 4, however, takes a relatively restrained approach to biotechnology. It acknowledges that it is

extremely important to be involved in the area; it must protect food inputs from companies which could develop genetically modified improvements and patent them. Thus, MNC 4 outbid a number of prominent companies to purchase a formerly government owned Cambridge based plant breeding and seeds operation. However, on the basis of financial and economic assessments and taking into account concerns about regulations and negative public opinion, the company is looking for incremental improvements in products rather than 'big bang' improvements. The company is especially sensitive to public opinion. As a supplier of finished products to the consumer, MNC 4 caters to public opinion more than companies who have little experience in dealing directly with consumers.

4.4.1. R&D AND MARKET STRATEGY.

MNC 4 holds that currently, more profit can be made from biotechnology by improving production processes than by going for 'big bang' innovations. This conclusion is informed by numerous factors. An economic model developed by the economic research department contributed to the decision.

MNC 4 does not promote itself as a 'high-tech' company, but rather as one which is continually offering improved performance. Although they have ensured that they have the resources and knowledge to compete should the technology become a major feature of production in the future, biotechnology has a much lower profile in this company.

In total, the company spent £332 million in 1988, a relatively small R&D expenditure if compared to MNCs 1 and 2 but a higher percentage if compared with other 'consumer products' companies. In the area of plant biotechnology, MNC 4 "usually feels comfortable with about 1-2-3% [of turnover]." Again, this represents a low level of

expenditure when compared with other companies in the study. One manager commented that "The industry average for plant biotech is about 7-8%. Indeed, [MNC 2] are running at about 16-17% on plant biotech, and I believe MNC 1 are up to 30%" but thought that these companies may have overextended themselves and that such a high level of investment expenditure would not be recouped in the field of agriculture.

Out of the interviews, three reasons emerged for the conservative approach to biotechnology. MNC 4 feels that it is a "marketing" and "consumer" organization. It does not define itself as "science-based", or see itself as a front runner in innovation. One manager went so far as to say that MNC 4 is actually aiming to be a 'second runner' in biotechnology. Second, MNC 4 companies are expected to make profits, limiting the amount that can be spent on R&D. Profit maintains the company's share price, which managers consider important and which acts as a check on R&D expenditure. One manager interpreted financial assessment of biotechnology in the following way,

> "if you say...that you're going to acquire companies that will develop biotechnology at a certain rate which is related to strategic long term initiatives then they seem quite happy. If you go out and spend a fortune on R&D and buying up companies and all the rest of it, I think they would start marking the share price down. I think [MNC 1] if you like is in that bracket, because they put so much into plant biotech, and now its becoming obvious to the stock market that the seeds business is not a big money spinner. So, can they afford all this R&D?"

Third, following on from the second point, MNC 4 thinks that its 'realistic' outlook on the rewards which can be reaped from plant and agricultural biotechnology, based on managers' perceptions that seeds is a low value area is more accurate than many of its competitors. This assessment emerged subsequent to MNC 4's purchase of a major plant breeding institute, formerly owned by the

government, which I shall call Planton. One manager said that pre-purchase evaluation of the business has been overly optimistic. Partly this is because government accounting procedures are very different from business equivalents. However, the overly optimistic outlook was common to a large number of chemical and food companies which had bought up seeds companies. One manager predicted that many companies, realizing the limited opportunities, would begin to limit their investment in agricultural biotechnology. "I think industry analysts are only just beginning to realize that this shake out is occurring." Increasingly, companies will come to see that the main reason to be involved in biotechnology is to defend existing interests. For MNC 4, defending their position in various markets is the main reason for investing in the seeds business and biotechnology; they are reluctant and cautious innovators. One manager thought that the area of food production and processing would become increasingly competitive as chemical companies looked for higher value outlets for products of biotechnology and pointed to MNC 2's production of slower ripening tomatoes as an indication of a coming trend. Existing patent law, whereby companies can patent genes and end use will also intensify competition and makes it essential for MNC 4 to invest. A major competitor works with

> "...a biotech boutique to develop oil seeds which are less saturated in their fat, then maybe they could produce a margarine which they could claim is 'natural', and maybe they can develop an oilseed that you can just squeeze it and out comes margarine at the other end...well anyway, less processing. So its cheaper and greener and you make quite a good marketing issue out of that - and they can patent it! And they don't have to give us the gene. And not only can they patent that - they can patent the margarine that's made out of it as well."

This thinking lay behind the purchase of Planton. A failed experiment with oil palms, initiated at central

research facilities led MNC 4 to conclude that it needed major input from experienced plant breeders before investing further in plant biotech. Managers' think that limited R&D spending on plant biotechnology will put the company in a position to bargain with competitors and 'swap' innovations, by licensing genes to each other. The concentration in plant breeding is on improving processing characteristics in plants, such as oilseeds and speeding up the process of plant breeding. Thus, the primary motivation behind MNC 4's biotechnology investment is to protect raw materials.

MNC 4 plans to avoid risks of the type taken by MNC 1 in terms of regulation and public opinion and are much more cautious in the products it is developing. In 1982, MNC 1 proposed that MNC 4 should join with them in developing BST. MNC 4 refused; managers thought that development costs would prove high and although milk quotas had not yet been introduced, milk production was already in surplus. They have not regretted the decision. The same decision would be made again, but now there would be another reason not to pursue the project.

> "We thought it was technically too difficult, too expensive, and it was not user-friendly to the farmer...it was just not our business - far too risky, but we did not consider the 'green' issue at that time, and I'm adding that on now...that would have been the no.1 factor if we were offered it today."

MNC 4 is keen to pursue development of biotechnology, only where there exists perceived 'need'. In most cases, MNC 4 focus biotechnology innovation on improving the quality of products and efficiency of the production process. The company sees that biotechnology can make contributions all the way along the production line, from improving raw materials to diagnostic kits which can detect signs for deterioration in packaged foods on the super market shelves.

While this strategy was emphasized by all managers, it is also true that MNC 4 is developing applications for higher value, lower volume markets and diversified into new business areas, on the basis of biotechnology. The establishment of a medical products division and development of pregnancy and ovulation kits is the prime example of this. Thus, the 'nothing new' line must be considered in light of MNC 4's PR approach, which is to down-play the impact of the technology.

One of the company's economists also saw that biotechnology might contribute to the emergence of 'grey areas' between sectors.

> "...if you look at the way the market, its moving more and more towards the grey area...Anti-aging, that is moving to the medical, whether its cosmaceuticals or pharmacetics, that kind of thing, its coming at it from both angles. And biotech can contribute to that...It has got a role to play in understanding how the skin works. In understanding what it is that makes the skin react in a particular way. And if we can then focus our research on producing enzymes, or whatever it is, to trigger reactions in the body, then it will build."

In order to seriously undertake this work, however, decisions would have to be made about where to locate R&D and who should fund it. To do the work in personal products division would require a culture shift from being purely consumer products oriented to undertaking serious R&D. Increasing concern with healthy food creates other possibilities for a 'grey area' between food and pharmaceutical areas. This appeals to food companies, keen to develop high value added food items and perhaps to pharmaceutical companies who could use their expertise to diversify into other areas.

4.4.2. ORGANIZATIONAL STRUCTURE.

MNC 4 central research labs are located in the UK (detergents, foodstuffs), USA (detergents and toiletries), Holland (edible oils and fats, detergents) and India (consumer and industrial products). MNC 4 divides its research between operating companies and central research laboratories. The amount differs according to the specificities of each company and each coordination. Operating companies have a high level of autonomy. They are charged a 'tax' for central in-house activities, but are also free to contract R&D to outside companies or institutes. MNC 4 central research labs also include services such as 'consumer science' research in order to establish demand matters and consumer preference. This type of research, then, is located at the same site as R&D and is considered to be a very important component of research activity.

Each company establishes its own research programme and its capital expenditure budget. However, all coordinations have a team of managers responsible for overseeing the business development of each company and unifying R&D efforts. During the eighties, as part of the overall strategic review, central research labs underwent major organizational changes. The aims included, reorganizing research groups according to new technologies and developments, simplifying structures, making them more accessible to operating companies and bringing the R&D facilities and operating companies closer together.

When I visited the central research labs in the UK, staff were participating in a Total Quality Management exercise which, it was hoped, would make the organization less hierarchical improve communication amongst different research groups and contribute to successful innovation. The exercise constituted a significant investment of time

and money, with each member of staff participating in a five day training programme and a series of exercises and projects over a period of a year.

4.4.3. COLLABORATIONS.

MNC 4 has relatively few R&D collaborative ventures and none with DBFs. The preferred method of acquiring skills is to acquire companies. Both central research and operating companies have links with universities and fund research projects and postgraduate researchers. R&D is done with universities all over Europe and the US. Projects are usually carried out in joint teams, made up of people from the universities and in-house scientists. This is a way of ensuring that projects run according to the company's plan. Thus collaboration is very much 'hands-on' and steered by the company.

4.4.4. REGULATIONS AND PUBLIC RELATIONS.

While they lobby for regulations that would suit them, according to some managers the company has created a strategy that can adapt to adverse regulations and public opinion. Because they are primarily working on improving existing products, they are more amenable to the idea that biotechnology should be subject to socio-economic assessment and a 'need' criterion (discussed in chapter 6). Their products have already proved themselves 'needed', in the sense that there is sufficient demand to make them profitable. One manager supported the creation of a European version of the US Office of Technology Assessment, although he expressed concern that this might serve to 'politicize' technology. MNC 4 managers were all aware of the political nature of regulations and the link between public opinion and regulatory regimes.

As part of a strategic review of biotechnology at the UK central research laboratory, managers ranked new

biotechnology products in terms of public acceptability. The list they drew up is included below:

RANKING OF MAJOR APPLICATIONS OF BIOTECHNOLOGY ACCORDING TO THEIR LIKELY PUBLIC ACCEPTABILITY.

MOST ACCEPTABLE.	Treatment of disease
	Medical Diagnosis *
	Environmental Protection
	Fermentation Technology *
	Biotransformation (Enzymes)*
	New Ingredients for Detergents and Personal Products *
	Improved crops/seeds *
	New Food Ingredients *
	Release of New Micro-Organisms *
	Animal Growth Hormones
	Pesticide/Herbicide Resistant seeds
	Transgenic animals
LEAST ACCEPTABLE	Human Eugenics.

Note: * indicates areas of MNC 4 interest.

The company, as noted, has been concerned about patent protection. Managers thought also that when patent legislation was finalized, providing that it allowed for the patenting of 'living things', innovation would speed up. One manager, who had been involved in a National Economic Development Office study of biotechnology, commented,

> "The view we gave about agribiotech to NEDO was that the availability of products and markets is not going to be delayed by technical constraints which has been the case in the past but more by legislative and environmental concerns. So, it's government legislation, patent legislation and consumer reaction. So, the industry needs to get its act together in its PR and I think its beginning to do that through the various bodies."

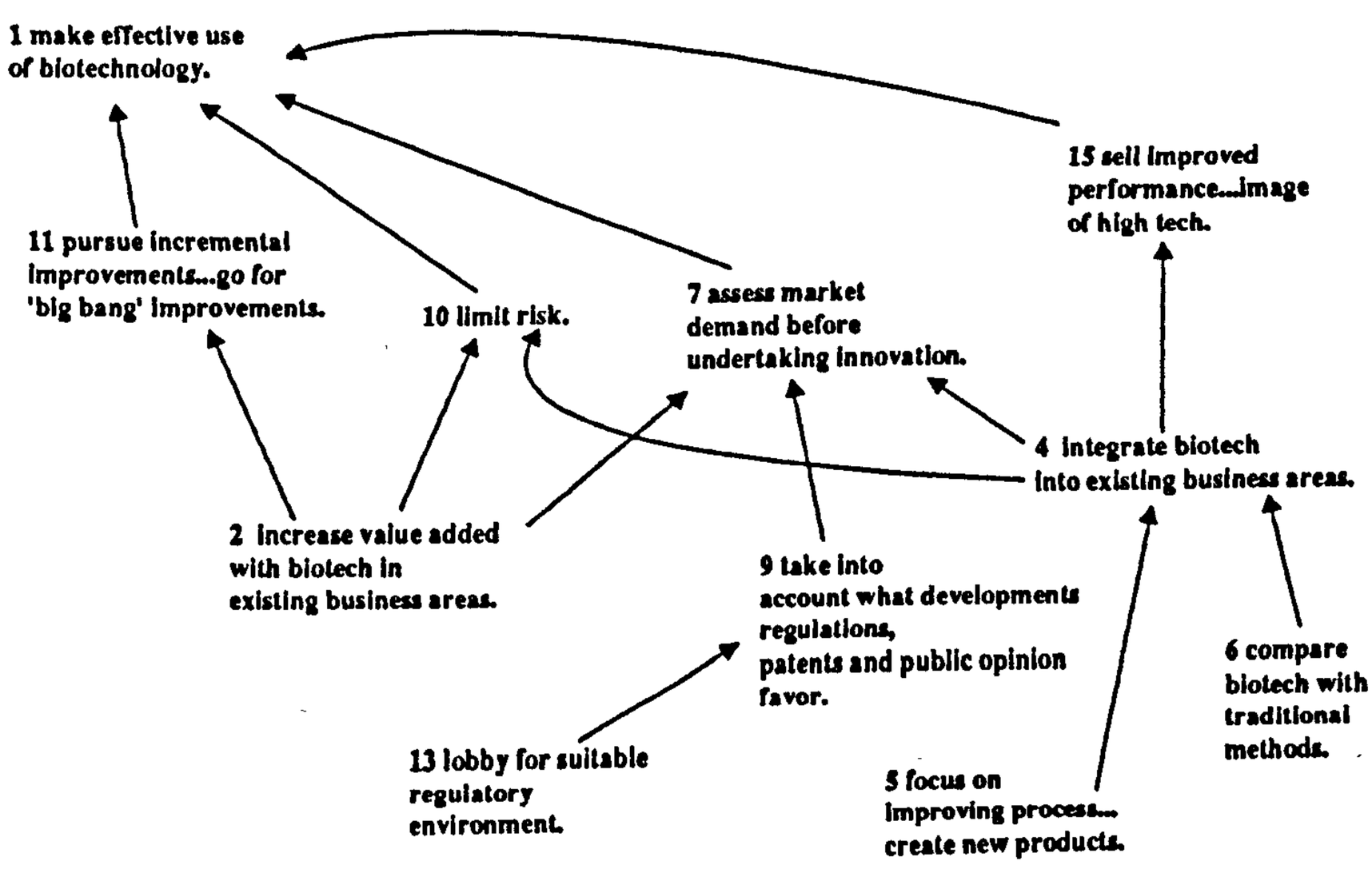
4.4.5. CULTURE.

MNC 4 has a strong culture which permeates throughout the company; there were high levels of consensus among managers about the direction of the company and the kind of biotechnology which was appropriate. 'Cultural' consensus

does not happen by chance or osmosis in MNC 4; during the eighties, top management tried to increase the degree of central coordination. But, also as a way of dealing with still relatively high levels of diversity and autonomy amongst a wide range of companies producing different products, the company stressed company culture as unifying force. This type of socializing and training programme, although expensive and time consuming, allows "the company to make this decentralized structure work, and yet still keep all the local operations marching in step."

In terms of the categories used to decipher other key differences between companies, MNC 4 is oriented toward security of profits, costs orientation, product excellence and consumer orientation. It is a growth oriented company, but growth with security is a priority. The company is not, in comparison with other MNCs in this study, primarily motivated by scientific and technological excellence.

4.4.6. COPE MAP.



Cope Map 4.4.

The COPE map portrays MNC 4's cautious approach to biotechnology innovation and its focus on incremental improvements and improved performance and process (concepts 15, 11, 2, 10, 5). Unlike MNC 1, in particular, the company is keen to follow the market and develop biotechnology in areas where market demand has already been established (concept 7), thus there is a strong tendency to integrate biotechnology into existing business. Comparisons are made between biotechnology and traditional methods (concept 6). While the company lobbies for preferred regulations, it is more responsive than MNCs 1 and 2 to the external environment, particularly public opinion and acknowledges that it may have to change strategy in response to external factors (concept 9).

4.4.7. CONCLUSION.

Key points arising from this discussion are as follows. First, MNC 4 is in a different mold to other MNC's considered. It is not a chemical company. As a food and consumer products company it approaches biotechnology innovation differently, with less emphasis on being at the forefront of technology and more concern with direct product applications and consumer perception. The company's mission has not been to research continually with new technologies, but to incorporate innovations to cut costs and improve existing foodstuffs consumer goods and to focus on marketing and image. Second, during the eighties, the company undertook extensive restructuring in order to remain competitive. An important component of change was an attempt to increase the level of R&D and bring central research activities and operating companies closer together. The challenge of new biotechnology gave the company a particular impetus to increase R&D in plant breeding and increase vertical integration in order to secure inputs of raw materials. The company has spent

considerable effort forging strong links between different parts of the production process and building upon existing strengths. Even its venture into previously uncharted waters with medical diagnostics, builds on its capabilities of large scale distribution of products and marketing expertise. Innovation in this company is clearly seen as a cumulative activity and one that emerges from learning by doing. Third, it has chosen to use the strategy of acquisition rather than collaboration to access new technology and incorporate new knowledge. Fourth, like MNC 3, MNC 4 is disappointed by limited profit margins in the Seeds business; unlike MNC 3, whose core business is oil, it perceives no option but to continue activities in this area. Fifth, MNC 4 sees that the constraints to biotechnology innovation derive from economic factors, risk regulation, patent legislation and public opinion rather than technical factors.

4.5. MNC 5. OVERVIEW.

I was unable to conduct as many interviews with decision makers in MNC 5 as I did with the other MNCs because relevant R&D is not carried out in Britain. Nevertheless, I acquired enough knowledge about the company, to warrant a section in this chapter. This firm provides some interesting contrasts with other chemical companies in the study.

MNC 5 is a state-owned French based chemicals company. It is the third largest pharmaceutical company in Europe and the fifteenth largest in the world. Agrochemicals contribute 25% of overall profit, and MNC 5 is among the world's 4 leaders in this field. The company had a turnover in 1988 of FFr 65.3 billion and FFr 3.5 billion profit. Despite, its leading market position, it takes a cautious approach to biotechnology innovation. Like many other agro-chemical companies, it invested

heavily in seeds companies, hoping to take a leading role in developing the technology. While the company reports and a published strategy document for the next ten years call for investment in seeds and plant breeding, management now seems clear that chemical based agricultural inputs will constitute the company's primary focus in the foreseeable future at least.

By comparison with other agro-chemical companies, its commitment to biotechnology is limited. In one of the main research stations in Lyon, there are only twenty people working, primarily on the development of herbicide resistance. There are other small biotechnology research stations in Britain and the US.

4.5.1. R&D AND MARKET STRATEGY.

Over the next ten years, MNC 5 plans to pursue the following targets:

> "Crop protection from 90% down to 70% [of sales], Seed Technology from 5% to 20%, and Garden and Amenity Care up from 5% to 10%. In absolute figures, each Division will continue expanding" (MNC 5,1990:3).

The Seeds business will proceed via two growth routes. 1) Seed treatment; 2) Genetic manipulation of seeds. Additionally, MNC 5 has identified three crops, maize, sunflower and soy-bean on which it will concentrate its biotechnology efforts.

The "mission" of the agricultural sector is spelt out as follows:

> "Optimizing plant production, by combining all approaches (chemical, biological, genetic, physico-chemical). The key word is innovation; making more and better investments, using our privileged links with French researchers to enter the international scientific community, and making use of all synergies provided by the Group" (MNC 5,1990:4).

Funding for R&D in the agricultural sector will come from agro-chemicals; seeds is unable to generate enough profit to fund its own research. R&D spending currently runs at 7% of agricultural division turnover (Chemistry and Industry,1991). Spending is expected to,

> "increase steadily (over 10%) for new products, projects under development and seed treatment; it will be greatly increased (doubled) for plant breeding, molecular and cellular biology, and plant physiology" (MNC 5,1990:6).

Although this programme sounds quite ambitious, all the managers interviewed were more cautionary about biotechnology's potential contributions. And all stressed that MNC 5 carefully limited its involvement. In terms of markets, it identified the US (corn and soy-bean) and France (sunflower). It also narrowed down technological developments; increasing the yield in major crops is considered important and biotechnology is used to identify useful genes and improve plant breeding methods. Herbicide resistance is a short term objectives. Pest and drought resistance are longer term objectives.

All managers also emphasized that they saw chemicals playing the major role in crop protection for the foreseeable future. They argued that while pesticides have a bad reputation, they are effective, relatively cheap and, at this point, very safe. One manager said that compared with the unknowns surrounding biotechnology, pesticides could be viewed as the more environmentally sound option. Another said, "All pesticides tend to be looked at as bad, but this is analogous to the philosophy that says 'all men are rapists'." The industry is "saddled with a reputation that it doesn't deserve", based on early pesticides. Another manager made the point that biotechnology research, combined with increased understanding about plant physiology, will likely improve chemical applications.

Distinguishing between MNC 1's and MNC 5's approach, an interviewee said that MNC 5 is not a technology driven company, whereas MNC 1 "has moved from being a one product company to being a biotech company." From the perspective of a British based manager, not directly involved in biotechnology R&D, MNC 5's commitment to biotechnology appeared "shaky" and he thought that recently acquired seeds companies might be sold off. This would depend on the pay back from biotechnology products and on the financial situation of the company as a whole. It would also depend on how the regulatory situation and public opinion evolved. While biotechnology could make useful contributions, particularly in developing countries, technical problems and economic constraints did not make it an attractive option.

In response to other companies grandiose claims that biotechnology could "Feed the World", he said economic constraints mean that, "There is very little interest in making the deserts bloom."

In addition, the general manager of the agricultural business in a published article indicated that while environmental concern was pressurizing companies to come up with new products, these were likely to involve more sophisticated chemistry. The article did not record him mentioning biotechnological alternatives.

Constant comparisons are made between the efficacy of different technologies. Biotechnology and greater knowledge of genetics have important contributions to make in improving process technology and research itself. Biotechnology is encouraging a move away from the "random spray and pray" philosophy in crop protection. It is making the process of plant breeding and crop protection more specific. Managers worried, however, whether niche marketing would generate sufficient profits.

However, while the company maybe focusing its efforts carefully, total withdrawal from the area of biotechnology seems unlikely. The director of biotechnology R&D, based in France, while noting the limitations of technology, made it clear that the company would pursue a range of biotechnology developments in maize, sunflowers and soy-bean. He also said that higher value/lower volume targets were ideal targets for biotechnology R&D. One of biotechnology's particularly attractive attributes is that, by increasing genetic and biochemical knowledge, it increases specificity. Thus, biological pesticides might be designed with far greater specificity than existing chemical solutions, to deal with specific plants, climates and pests. Or plants could be engineered to resist specific insects and disease. However, while this would certainly be lower volume, the manager was worried that products would not have a high enough value to recuperate money spent on requisite R&D.

About 10-20% of research funds is spent on work designed to give "windows on technology." This component of research is much more technology driven. At a certain point, market criteria are applied and decisions about further development are taken.

Like an interviewee from MNC 3, this manager stressed the need for better understanding of ecology and plant physiology. He stressed that while genetic manipulation had become relatively easy, this would not prove a panacea for all further development. "Genetically altered plants have to be tested in the field as plants obtained through conventional breeding to check their agronomic behaviour." Thus, the focus of research has to change from a narrow genetics focus to an approach that aims at understanding the entire organism and its interaction with the environment. These issues constitute the main technical problems currently. He also emphasized that while in-vitro

techniques can speed up plant breeding a little, it remained a drawn out process.

4.5.2. ORGANIZATIONAL STRUCTURE.

The MNC 5 group revolves around three technological axes: life sciences applied to humans, animals and plants; new materials and speciality chemicals; and organic and inorganic intermediates. The company is divided into four divisions: chemicals, health, agrochemicals, and fibres. The agrochemicals division hosts two other businesses; seeds and the garden and amenity business.

The French government nationalized the company in 1982. Also, during 1982, the company reorganized its R&D and business functions; one of the changes was that R&D is now done on a divisional basis. The need was felt to bring R&D closer to other stages of the production process.

The agricultural division has R&D facilities in three countries, Britain, France and the US.

4.5.3. COLLABORATIONS.

MNC 5 does not have significant collaborations with DBFs. It does have extensive contact with universities and research institutes in France, Britain, the US and Japan. Work is done in universities for two reasons. First, the company prefers do to more fundamental work in universities and secondly, so that there will be a pool of trained people to employ in the future. At the beginning of the eighties, there was a shortage of skilled people in the area of biotechnology, but now that companies and universities had stabilized their research programmes and filled their quotas of biotechnology people, skills shortage would not be a problem in the future.

4.5.4. REGULATION AND PUBLIC RELATIONS.

The cost of regulations will make a difference to the amount of biotechnology R&D which is undertaken; one of the incentives to undertake R&D in the area is that regulatory costs for biotechnology-based products will be less than for chemical counterparts. If this is not the case, there will be less incentive to undertake innovation. Although it is a member of SAGB, in terms of promotion of biotechnology, it takes a lower profile than some other companies in the study. Additionally, fewer claims are made in the company's public literature about biotechnology being 'natural' or 'green' or its ability to solve world hunger. MNC 5 is not a company which has committed huge resources to developing biotechnology, therefore the situation for interviewees seemed relatively clear: if regulatory costs are prohibitive, the amount of biotechnology R&D will be reduced accordingly.

Recently, however, the company encountered considerable opposition to one of its new insecticides in the US and there is a significant probability that the product will be banned. This may give biotechnology research within the company a new impetus. However, given managers' skepticism; this should not be assumed.

According to an interviewee based in France, there is no evidence of public opposition to biotechnology in France and very little concern about its impact.

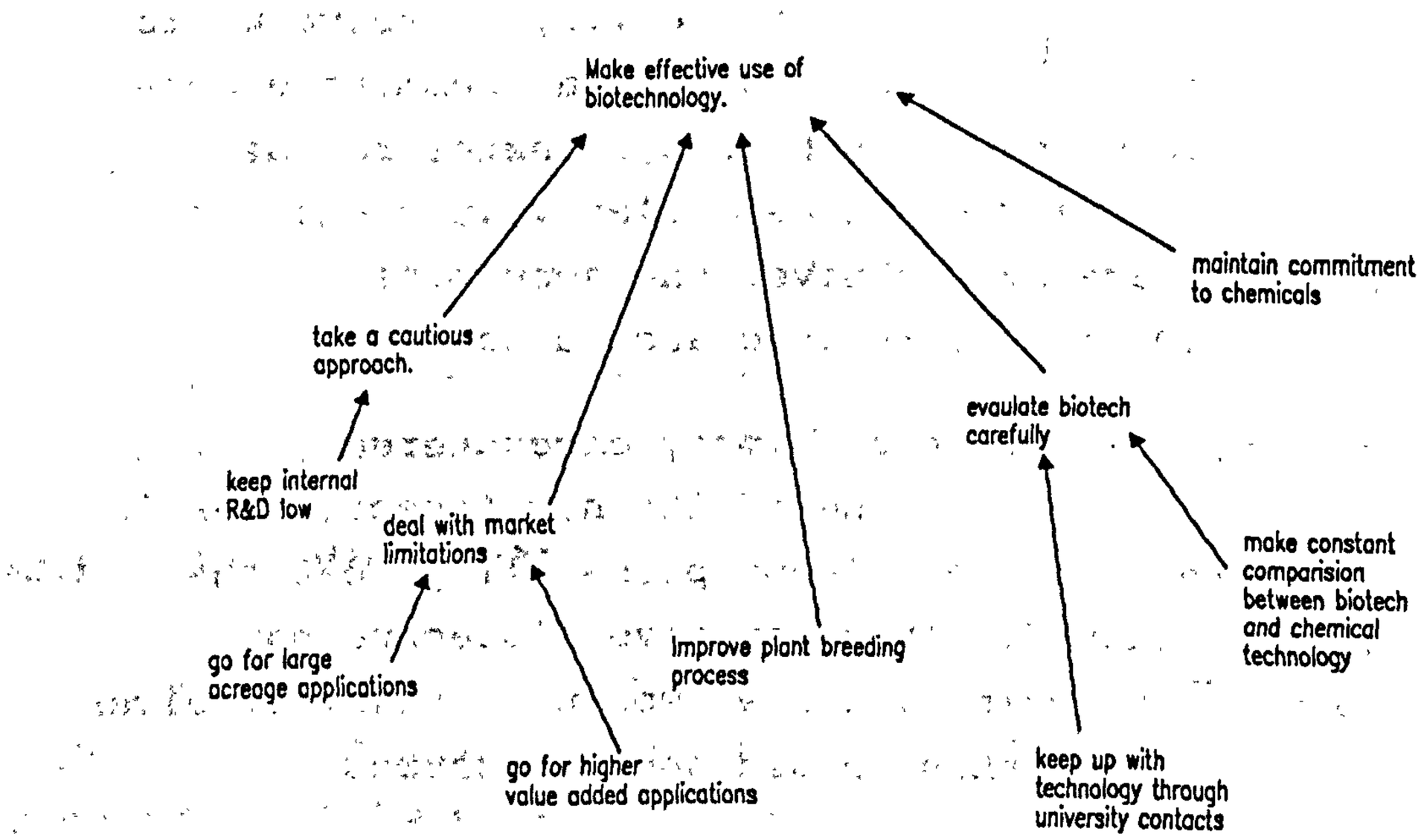
4.5.5. CULTURE.

Limited time spent in the company did not leave me with sufficient information or 'sense' of the company to make broad comments about its culture. However, clearly MNC 5 is not aiming for scientific and technological excellence so much as it is product oriented. This seems

to be a key distinguishing factor between this company and other agro-chemical companies which are developing agricultural related biotechnology.

Managers said that being state owned made no difference to the way in which they made decisions about biotechnology. However, it may be that the financial security afforded the company, gives it less necessity to 'hype' the technology; MNC 5 does not have the pressure to maintain its share price.

4.5.6. COPE MAP.



Cope Map 4.5.

The COPE map shows the MNC 5's careful approach to biotechnology (concept 4, 2) and its relatively low levels of R&D spending in this area (concept 8). It is targeting high value applications and large acreage crops, but on a smaller scale that MNC 2. It is also using biotechnology to improve the plant breeding process (concept 7). MNC 5 makes constant comparisons between biotechnology and other technologies and is not interested in replacing chemical technology, unless biotechnology can prove itself

technically and economically superior (concepts 4,5,3). The company collaborates with universities in order to keep up with the latest developments (concept 6).

4.5.7. CONCLUSION.

Key findings are as follows. First, MNC 5 appears wary about biotechnology's contribution to its agricultural division, at least in the short term. MNC 5 is convinced that for the foreseeable future conventional plant breeding and chemical based crop protection technology will continue to dominate agricultural production. In most instances, biotechnology cannot compete with chemical applications in the area of crop protection and in the area of plant breeding, more needs to be understood about plant physiology and ecology before genetically engineered plants can be made to operate efficiently. Second, it does not seem that MNC 5 is overly concerned with building up technology for strategic longer term purposes. Its perception is that it's strong arsenal of chemical products will continue to be the primary breadwinners in the foreseeable future. This perception clearly differs from those of 1 and 2. Third, and perhaps relatedly, the company does not perceive itself as a 'science-based' or 'technology driven' company. It sees itself as responding to market forces. Fourth, managers saw that the science of genetic engineering alone would not lead to new products; emphasis was placed on integrating the new science with more ecological knowledge and more tacit plant breeding knowledge.

4.6. GENERAL CONCLUSIONS.

These company studies portray a diversity in companies' approach to biotechnology innovation. This variation demonstrates the pitfalls of using 'universal' models to account for patterns of innovation. The

following table portrays some of the key charactristics of each firm.

Table 4.1. MNC CHARACTERISTICS

	MNC 1	MNC 2	MNC 3	MNC 4	MNC 5
R&D AND MARKET STRATEGY.	Create radical new technologies and markets. Technology driven.	Targeted development of new products, product and process improvement. Product Driven.	Niche markets and development related to core activities. Withdraw from seed biotechnology.	Incremental innovation. Improvement of existing products and processes.	Cautious innovators. Primarily improvements in existing process and product improvements.
ORGANIZATIONAL STRUCTURE	Central R&D facilities. Organization revolves around core technology.	Decentralized R&D facilities. Small unit to develop biotechnology innovations.	Highly autonomous business units. Central research facility.	Central research laboratories. Relatively high levels of autonomy in operating units.	R&D carried out on divisional basis.

	MNC 1	MNC 2	MNC 3	MNC 4	MNC 5
COLLABORATIONS	Widespread collaboration with universities and DBFs.	Collaboration with universities, not with DBFs.	Collaboration with unviersities and highly selective collaboration with one DBF.	Collaboration with universities not with DBFs.	Collaboration with DBFs and limited joint work with DBFs.
REGULATIONS AND PR	Support reactive regulations. Very active in promoting biotechnology.	Support reactive regulations. Active in promoting biotechnology.	Uninvolved in political controversies surrounding biotechnology.	Keen to follow public opinion, lower profile in promoting biotechnology.	Low profile in debates about regulation and promoting biotechnology.
CULTURE	Scientific and technological excellence. Growth orientation.	Scientific and technological excellence. Product oriented.	Security of profits.	Security of profits, costs orientation, product excellence, consumer orientation.	Product oriented.

The chapter relates to points made in chapter 1 in a number of ways, some of which will be briefly discussed here. The final chapter elaborates on theoretical perspectives.

Clearly, firms' R&D decisions, far from being based solely on economic criteria, are highly political and social decisions and are recognized as such. One of the fascinating aspects of biotechnology innovation is the way in which external political and social factors combine with firms' internal cultures and political evaluations. The 'politics of innovation' partially explains the variation in the firms considered in this chapter. In the case of biotechnology, MNCs are dealing with many unknowns and a volatile social, political and regulatory situation and negotiating this environment constitutes an important aspect of biotechnology innovation.

Large companies had considerable advantages over their smaller counterparts in being able to produce innovation. Not only did financial strength increase their capacity to innovate in important ways, their economic and political muscle are used to promote the technology and to exert pressure for friendly regulatory environments. Large firms have the power to shape and create markets which small firms do not. Their resources also gave them opportunities to experiment in certain areas and to fail. They had the capacity to make biotechnology more efficient by combining it with other technologies, such as advanced microelectronics and chemistry. Most importantly, perhaps, they had enormous technical expertise, relating to production, marketing and distribution, for instance, which could be integrated with the new science. However, their size also posed problems. As some managers admitted, small firms, close to the scientific base, had been quicker off the ground and had advantages in terms of flexibility. Additionally, biotechnology creates opportunities for

further specialization in agricultural inputs and foods. On the one hand, the idea of niche marketing in lower volume/higher value areas appealed to managers, but they were unsure whether a large firm could reap large enough rewards to make this activity worth their while in the area of agriculture and food. Also, managerial problems arose in relation to trying to extend the global reach of the company, while taking local conditions into account.

Biotechnology innovation has specific properties and involves a different set of socio-economic conditions from microelectronics for example. It also involves high risk R&D with long lead times. The structure of agricultural and food markets shapes R&D and strategic decision making in a specific way. The social infrastructure of regulations and patents remains controversial and uncertain. Thus, Amendola and Bruno's characterization of innovation as a process of change in both the environment and firm seems particularly appropriate in this instance. They say;

> "...innovation is a process that should be considered as a *change* of the environment of the innovating firm rather than something occurring *within* this environment and, more in particular, as a learning process which concerns both the firm and its environment and that results in deep changes in both of them" (Amendola and Bruno, 1990:419).

The differences between the way in which firms innovate can also be explained by looking at which sector they are in and their place in that sector. MNC 4, a 'consumer goods' company with a large presence in the food industry had a very different approach to innovation than MNC 2, a 'science-based' chemical company, or MNC 1, a "technology driven" company. Sectoral innovation requisites differ considerably. This bears out Pavitt's observations (1984) about the differences in patterns of innovation in different sectors. However, if we look more

closely at the companies studied here, it becomes clear that the level and nature of innovation cannot be deduced from sectoral characteristics.

One point is that the nature of sectors change as do boundaries between sectors. MNC 4, a company located in a low innovation level sector, undertook massive restructuring during the eighties with a principal aim of increasing levels of innovation. While it takes a more cautious approach than many of the chemical companies, it is moving in the direction of increasing levels of R&D and reorganizing internal structures on that basis. Increased competition in seeds and plant breeding and potential changes in patent legislation influenced these decisions. The prospect of new areas of activity, such as diagnostics and pharmacuetics, provided additional impetus to increase R&D funding.

Within the chemical sector, companies displayed considerable variation. This can be partially accounted for by looking at a company's position within the sector and the importance of agro-chemicals and seeds in relation to its other activities. One of the intractable problems of agriculture or food related biotechnology innovation, is the scale of investment needed to make a difference and the commitment needed to cope with a technology that poses a myriad of managerial difficulties. In order to recoup R&D costs, MNCs found it necessary to pursue R&D in both the large acreage crops and high value/lower volume markets. In order to achieve the first objective, large companies must make sure that they have seed companies located in appropriate geographical locations. However, they also have to find ways to diffuse centralized R&D activities. In order to the accomplish the second, MNCs, unwilling to diversify too much, may have to enter into new collaborative relationships or increase levels of vertical integration. The economics and management issues involved

in these decisions are complex and time consuming. In the case of MNC 3, the costs and risks attached to such investments were not worth taking. Seeds were far from essential to its core business and loss of market share in the agro-chemical sector due to herbicide resistance or other biotechnology developments would not damage 'core' operations in any way. One way of looking at it is that MNC 3 did not invest heavily in agricultural biotechnology because it did not have to. In stark contrast, MNC 1, with its reliance on two agrochemical products for 60% of its profits, had little choice.

MNC 1 had everything to gain by diversifying its technological base. It committed itself fully to biotechnology. In many ways, this company has constructed a very productive organizational structure for biotechnology innovation. It combined very significant in-house facilities and highly qualified in-house scientific staff with a network of collaborations, following a 'Post-Fordist' strategy of building relationships with specialized, small and flexible 'suppliers'. This company has come the closest to creating a new, or more accurately, parallel hierarchy of small firms which contribute to its R&D effort.

This company, with its heavy investment in science and technology should, perhaps, have the best prospects for successful innovation. It is too soon to say whether this prognosis will be proved entirely wrong. It is not too early to see why MNC 1 could fail. MNC 1's current problems relate to its lack of political judgement and, with hindsight, dubious interpretations of economic trends. In a sense the company pursued a 'technology driven' strategy rather being informed by the market, or by the political and social situation. While MNC 1 appears to have adopted a creative and, in important respects, non-linear approach to technical and organizational factors, it

has failed to consider the social and political factors essential to successful innovation.

With respect again to diversity of strategy, MNCs 2 and 5 make an interesting comparison. In terms of the areas of activity and their place in sectors, the companies are very similar. Their biotechnology strategies, however, are quite different, with MNC 5 pursuing a much more cautious approach. Cultural factors and different orientations of firms are key to explaining these differences.

This study clearly highlights, in a number of instances, the fact that innovation is a cumulative activity. In a sense the whole thrust behind much of plant biotechnology relates to the need to protect previously established markets. Instead of buying in diverse elements of technology, which would fit specifically into previously identified markets, however, both the chemical companies and the food company in this study have opted to acquire already established seeds companies with considerable experience on which to build.

There are other, more specific examples of the importance of accumulated knowledge and experience of the development end of R&D. In the case of the MNC 2, one of its first biotechnology products, the meat substitute, came from a previous venture which proved a commercial failure. The technical achievement, which mainly related to scaling up activity, not the science of fermentation, found a commercial outlet in the form of a very different product from the one originally intended. MNC 1's development of rBST related to previous work in the pre-genetic engineering era. This description of how decisions relating to this development came about also portray it as an instance of innovation coming from 'learning by doing'. MNC 3's continued work with biopesticides relates to previous involvement in the area. Its decision to build up

its forestry activities was based largely on its interests in energy and biomass.

On the other hand, the cumulative nature of technological change does not, by any means, explain all innovations or decisions relating to R&D strategy. MNC 4 diversified into diagnostics, an area in which it had no previous experience and innovated successfully. In a negative sense, MNC 3, decided not to pursue innovation in seeds, even though it had considerable existing investment and expertise in the area. And the example of MNC 2's meat substitute product as an instance of cumulative knowledge leading to innovation is not so simple; while the final innovation was in some respects the product of previously acquired technical knowledge, MNC 2, in addition to building on past work, set up a small company within a company in order to limit the extent to which past activity determines the future. Thus, the company tried both to take advantage of its capacity to 'learn by doing' and to create new opportunities by 'learning to undo' structures which inhibited innovation. MNC 1 does this through constant monitoring and fostering of smaller companies.

Another interesting aspect of the diversity amongst companies was the variation in organizational structure. All the companies, with the exception of MNC 3 had recently undertaken some reorganization of their R&D functions. There are no simple correlations between organizational structure and rate or direction of innovation. However, the evident tension between centralizing and decentralizing research activity and between the desire to make research 'market led' and yet retain creative activity is related to a company's desire to accumulate knowledge, on the one hand, and remain open to new areas of activity, on the other. The degree and type of contact between different sections of the company is a central management dilemma. Companies restructure in order to compete with new

technologies in increasingly competitive environments. Biotechnology, still close to the scientific base and spanning several sectors was one of the factors which caused companies to rethink the organization of R&D within the companies. Companies pursued different strategies in terms of connecting more basic research with different parts of the company and created a variety of balances between more fundamental work and further down stream development activity. In turn, the study provided several examples of the impact of organizational structure on firms' innovation patterns. The fact that this is a continually difficult aspect of management is another indication that the linear model of innovation is lacking; companies realize that the issue is not simply how much is spent on R&D, but that issues of centralization, decentralization, nature of collaborations, degree of in-house work, balance of targeted research and more fundamental work are very important.

CHAPTER 5. INSTITUTIONS, MARKETS AND INNOVATION.

In previous chapters a tension between the potential of biotechnology to create new products and the ability of DBFs to get innovations to market became apparent. Organizational and cultural factors which impacted on large firms' capacity to innovate were also identified. Additionally, fieldwork demonstrated that both large and small firms are uncertain about opportunities in agricultural and food markets. Together with emerging regimes of risk regulation and patent legislation, changes in institutions and markets are important components of more systemic changes (changes in the regime of accumulation if the language of the FRS is adopted); biotechnology is both molded by and influences these broader changes. Chapters 3 and 4 examined innovation from the perspective of the firm; this chapter, together with chapter 6 explores the interaction between the firm and external environment from a wider angle which tries to include a wider range of actors.

Sociologists and economists widely agree that both science-push and market-pull are necessary for successful innovation (Hacking,1986, Coombs et al,1987). Both contribute to the rate and direction of innovation. Both derive from a combination of public and private institutions and policies. In the case of agriculture and food related biotechnology, aspects of both science-push and market-pull have proved problematic. This chapter

looks at changes in the relationship between universities and industries, and inter-firm collaboration; and between the public and private institutions which drive the 'science-push' aspects of biotechnology innovation. Although these changes would appear to contribute to scientific and technological exploitation of basic findings, the inability of DBFs to tackle other institutional hurdles and organizational difficulties in large firms have limited the extent to which these changes encourage rapid and radical innovation.

Biotechnology innovation is occurring at a time of more generalized industrial restructuring. Additionally, the technology itself offers new opportunities which will likely provoke further institutional change. The first section of this chapter considers the broader institutional system in which biotechnology innovation is occurring and discusses the interaction between institutional change and innovation.

The second part of the chapter looks at key aspects of agricultural and food markets. These markets are politically sensitive and public policy has played an important role in shaping them. Market and industry structure also influence the shaping of biotechnology and this section examines the dynamic interactions between markets, industry and the new technology.

While the chapter is divided into two parts, it is useful to consider these features of innovation together; institutions and markets both form part of a system in which innovation occurs and each component of the system affects the other.

5.1. INSTITUTIONS AND INNOVATION.

5.1.1. UNIVERSITY/INDUSTRY AND INTER-FIRM COLLABORATION; NEW FORMS OF TECHNOLOGY TRANSFER.

New biotechnology emerged at a time when broader economic trends favored closer relationships between industry and academia. Not only was competition becoming more dependent on increased scientific and technological input, giving companies an incentive to increase their R&D budgets but laissez faire economic policies and cut backs in state support also encouraged universities both to seek out industry funding and become increasingly entrepreneurial. Biotechnology, close to the science base, contributed to the changing relationship between universities and industry in a number of ways. First, it encouraged increased industry investment in universities. University scientists have not, generally, been attracted by large firm environments and MNCs have had very limited success in attracting top scientists and bringing them 'in-house' (Orsenigo, 1989). Moreover, scientists working in biotechnology, which broke down disciplinary boundaries, tend to work in teams, making it more difficult for large firms to buy up skills and knowledge by making them company employees. Thus, large companies contracted out work to universities and set up longer term collaborations. Second, university academics, attracted by prospects of commercial success became more adept at selling their R&D skills, forming 'hybrid' institutions to bridge the gap between academic institutions and industry and a number became fully fledged entrepreneurs, forming DBFs. While academics often resist large firm environments, smaller firms in which they held equity stakes, had more control and were more flexible, proved more attractive.

Increased collaboration between university and industry took place in the context of public policy initiatives to further commercialize science. The contribution of science to economic growth has a long history (Webster and Etzkowitz, 1991:5). In the post world war two era, as production and competition became more intensive, depending increasingly on advances in science and technology, western governments became more preoccupied with creating links between universities and industry. The common view which directed these policies in Britain was that Britain was good at science but bad at commercial development. During the post war years, government funding for basic science rose and so did its efforts to encourage technical change.

> "With the rapid growth in funding of science and technology after the Second World War, and the growth of all economic and industrial policy, largely as a result of the enthusiasm for Keynesian demand management, government involvement in technical change expanded considerably" (Coombs et al,1987:223).

The 'science push' attempts to induce innovation by funding basic science reached the height of its popularity under Wilson who promised to deliver a Britain "forged in the white heat of this technological revolution" (quoted in Coombs et al, 1987:224). However, the results in terms of increased competitiveness were limited. Studies done during the seventies established that simply pouring money into R&D would not guarantee innovation. Efforts were then made to plan innovation more effectively, identifying 'demand pull' on a sectoral basis. These efforts were institutionalized in bodies such as the National Economic Development Office (NEDO). Conservative governments, particularly the Thatcher government, have taken a much more laissez faire approach, believing that private industry should play the central role in developing new technologies. Nevertheless, policy was still aimed at

increasing collaboration between scientists and industrialists. Privatization of research, both in the sense of selling public research institutions and increasing private contributions to R&D, was a key policy tool used by the UK government during the eighties. Webster and Etzkowitz note that, "Relative contributions to GERD [Gross Expenditure on Research and Development] by government and industry have shifted since the 1970s such that private enterprise is now the major source of research funding" (Webster and Etzkowitz, 1991:6). Industry investment in universities has increased in Britain during the 1980s as government cut back funding in relative terms and encouraged universities to collaborate with industry. Business was not only encouraged to form closer links with universities, universities themselves became much more entrepreneurial, spawning off high technology firms and managing their R&D in a much more commercially astute way.

In the UK, from 1981 to 1987, industry's contribution to UK public sector research science (PSRS) rose from £51 million to £119 million (1985 prices) (Webster and Etzkowitz, 1990:6). Webster and Etzkowitz point out that while the amounts are small, the trend is significant. The NEDC emphasizes that while UK industry contributions have risen, they have done so at a much slower pace than in other European countries (NEDC,1991:76). One of the major concerns of authors of the NEDC report is the shrinking skills base in Britain. Basic science has to be maintained in order to be able to compete in biotechnology. Additionally, transfer of technology to business environments has to be made more effective (NEDC,1991).

Initial concern about commercialization of biotechnology in the UK followed the failure of any British company to exploit the Medical Research Council's (MRC) discovery of Monoclonal Antibodies (MAbs). In addition to spontaneous collaborative agreements between industry and

university, both interested in using research to increase profitability, government bodies directly encouraged and established various business ventures. Celltech, a DBF, was established shortly afterwards with the remit of exploiting MRC research. The company had, until recently, first refusal on all MRC discoveries. The Agriculture and Food Research Council (AFRC) had a similar agreement with the Agricultural Genetics Company. Both Celltech and AGC also had financial support from the government. Another DBF, Animal Biotechnology Cambridge benefited from less formal agreements with now privatized parts of the AFRC. Other moves taken by the public sector to facilitate technology transfer include setting up various LINK schemes which promote collaboration between University and industry and encouraging schemes such as PROSAMO where a number of industrial and academic teams work on biotechnology risk assessment. A Biotechnology Directorate was established in the Science and Engineering Council and a Biotechnology Unit was created in the Department of Trade and Industry. Science parks and interdisciplinary research centres (IRCs) were also created with the aim of furthering collaboration. Additionally, the government had a more decisive solution to the problem of transfer and collaboration between public and private bodies; it sold off a number of government research institutes, one of which was bought by MNC 4.

Universities established various institutions and mechanisms through which scientific discoveries could be commercialized. Apart from spin-off companies, "...an important development has been the steady though stochastic growth of hybrid transinstitutional structures that combine academic and industrial R&D activities" (Webster and Etzkowitz,1991:15).

5.1.2. DBFs AND THE LIMITS OF THE LINEAR MODEL.

Biotechnology is an extremely science intensive activity and there is no doubt that the level of scientific skills and the establishment of new transfer mechanisms played a key role in promoting innovation. Orsenigo contends that levels of appropriate basic science skills and superior transfer of technology in the US gave that country a significant advantage (Orsenigo, 1989:73). However, it is likely that the latter issue has proved more important than the former. Greater experience in collaboration between industry and academia and greater openness to entrepreneurial activity in US universities, not to mention greater access to qualitatively superior venture funding probably contributed even more to the relative success of biotechnology innovation than the quality of the science base; UK DBFs also in many instances had excellence of science on their side and yet, as this study has shown, were still confronted with formidable problems. This thesis shows clearly that the new mechanisms for transferring technology established in Britain have proved problematic. UK DBFs encountered numerous problems in trying to commercialize research and their experience demonstrates the limits of the linear model of innovation, which places prime importance on the supply and transfer of science, rather than at the production end of innovation. DBFs were confronted with technical, production and managerial constraints in product development. A number of managers acknowledged that while they possessed superior scientific expertise and their companies had creative and innovative environments, technical and managerial development constraints were extremely worrying. The linear model idea that, with the right scientific and managerial skills, science can be 'made' into technology and transferred into commercially successful products has to be called into question, even in

such a strongly science based technology. This is not to say that DBFs cannot succeed; there are some instances where companies have had some success as demonstrated in chapter 3. However, the findings of this study suggest that success is not simply the product of the quality or quantity of science made available, but depends on financial, managerial and technical development skills relating to scale up and production. Successful innovation is the product of interaction between stages of production; the nature, shape and commercial value of technology changes as a result of this interaction. Thus, while the changing role of universities gave impetus to the creation of DBFs and facilitated technology transfer via these companies, the increasing availability of scientific discoveries for commercialization does not lead directly to problem free innovation.

5.1.3. LARGE FIRMS AND NEW FORMS OF COLLABORATION.

Over the last decade large companies have invested heavily in the technology and built up significant in-house experience. The following table shows the change in the institutional origin of genetic engineering literature published by universities, research institutes and companies over the period 1980-1985.

TABLE 5.1. INSTITUTIONAL ORIGIN OF GENETIC ENGINEERING LITERATURE. (%)

	Universities		Other Institutes		Companies	
	80/81	84/85	80/81	84/85	80/81	84/85
USA	80	52	15	17	5	30
Japan	45	59	35	16	8	25
Europe	44	45	52	35	4	20

Source: Orsenigo (1989), Stankiewicz (1986).

The trend toward increased in-house activity by companies does not mean that university or extra mural research will become unimportant; companies constantly need outside scientific input. In a field as diverse and complex as biotechnology even large companies cannot hope to bring all relevant research in-house. The combined pressures of increasingly science and technology intensive production and the broader changes in the balance between private and public funding of R&D have been significant influences in the way large companies have managed their biotechnology innovation. The companies in this study showed a diversity of approaches to the new situation.

MNC 1 invested heavily building up in-house R&D facilities, collaborating with universities and DBFs. As noted in earlier chapters, collaborative ventures form an important element of MNC 1's biotechnology strategy. The company invests directly and indirectly, via its venture capital company in DBFs. It also has considerable long term research collaborations with universities. For example, it has invested $100 million in Washington University over a period of 12 years and $20 million in Oxford over 5 years. In return for its investment, the company gets commercial rights to potential discoveries or inventions. The fact that money is provided over a longer term also means that university research will be more directed by the company. Webster and Etzkowitz, however, do not think that firms will be able to fully dictate the direction of research, rather research programmes will be the result of negotiation between the two types of institution. They describe the terms under which longer term collaborations take place as follows.

> "...while companies will only support research that complements their long-term development plans, this research is - where it is not directly contract-research focused on a very specific applied problem - normally within areas where the science or at least its technological application is still relatively immature such that the sense in which agendas could be set is less obvious. The objective behind collaboration is often to fund long-term work in as broad a way as possible and to avoid interfering with scientists in the labs: it is often said that this would kill the goose that lays the (genetically engineered!) egg" (Webster and Etzkowitz, 1991:31).

MNC 2 also favored this broad thrust approach to financing university research, although on a significantly more limited scale. This approach, which moves away from more traditional arms length transactions, while costly, may have advantages over more piecemeal collaborative strategies. This type of collaboration allows for the tacit dimension of both science and technology development, which is not transferable in the same way as a research paper or machine. Again, Webster and Etzkowitz say,

> "...technology has a tacit dimension wherein professional expertise and technical skills are brought to bear on a particular problem, a problem which is then only likely to be resolved through the direct interaction of technologists. Policies for collaboration may or may not recognize this: those that do acknowledge the elasticity of the technological boundary within which the collaborative agreement can work" (Webster and Etzkowitz, 1991:19).

MNC 1's approach to collaboration has much in common with the approach taken by Japanese companies, which tend to invest large amounts of money in universities over longer periods of time. There is also a similarity in the approach to collaboration with other companies, as noted in chapter 3. Roberts and Mizouchi (1989) in their study of biotechnology strategy in Japanese companies suggest that longer term collaboration with other companies is partly

based on a recognition of the importance of tacit knowledge and particular cultures which develop in research teams[1].

The other large companies in this study took a variety of approaches to collaboration, both with universities and DBFs. MNC 3 had a significant collaboration with one DBF, but this was pursued for specific purposes[2]. It did not represent a strategic change in the way the company approached collaboration with other companies. MNC 4 collaborated with universities and outside research institutes but not extensively. Neither of these companies had significant collaborations with DBFs. MNC 5, a French firm, had extensive links with universities and research institutes, but did not have significant collaborations with DBFs. However, given the lack of data about this firm and the context it was operating in it is not possible to discuss the company's approach to collaboration in detail[3].

MNC 2 had extensive links with universities and research institutes. In addition to funding given to departments and established academics, the company funded a large number of postgraduate students[4]. Moreover in developing the slower ripening tomato there had clearly been an ongoing relationship between company and university in developing the technology. MNC 2's decision to establish a small company, within the large corporation,

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1 Another primary reason is that collaborative ventures can reduce the cost and risk of innovation (Roberts and Mizouchi,1989).

2 MNC 3 collaborated with a US based DBF in order to develop and market biopesticides.

3 It is likely that MNC 5, a nationalized company France which has a more interventionist industrial policy than the UK or US is in a different position from other companies in the study.

4 MNC 1 funds about 230 CASE awards. CASE funding for postgraduates is split between government and industry.

which would collaborate extensively was an innovative move and which recognized the limits of the larger company's ability to buy in appropriate knowledge.

However, all three British based companies had a clear view of universities and research institutes as suppliers of fundamental research. Most of the managers I talked with in these firms expressed concern at the cut backs in government funding of basic research. Many of them were worried that industry would have to increase its level of funding. They also expressed concern that universities would be pushed into doing more applied research as a result of increased industry funding. This would, in the longer term work against industry; the more fundamental work upon which industry builds would not be available. Cut backs in funding to universities must constitute a real threat to the UK's science base, but managers' concerns must be seen in the context of a widespread belief in the linear model of innovation. Managers see the university as being a repository of knowledge which they can tap into. However, if the model is called into question, the issue of availability of 'fundamental' science must also be viewed differently. Recent studies suggest that innovation is often the result of a more iterative process, which requires constant communication between different parts of the production process (Massey et al, 1991; Best, 1990; Webster and Etzkowitz, 1991). Initial discoveries, may open up new possibilities in technological terms (such as the discovery of the double helix), but sustained and successful innovation requires communication between scientists and those involved further downstream in the production process, such as engineers, technicians, designers and salestaff.

The view of many managers in large British firms seemed to tend toward the Taylorist view that conception

and execution must remain separate. Universities represent the uppermost point on a linear continuum which churns out basic ideas which feed through to product development. Given this and the traditional approach taken to collaboration with universities and other companies, the status of university based research is considered key. The worry about future lack of skills and basic science is echoed in a recent report by the NEDC (1991). The risks of a decline in the science base are stated strongly in the report. However, the conclusion to the section on 'The Science Base In Biotechnology', seems strangely incongruous with the overall argument and contains a reference to Japanese success which is curious. The report says,

> "It must be accepted that in technology generally, the UK weakness has been in the translation of discoveries into commercial products. Nevertheless it must also be accepted that a strong 'science base' is necessary to ensure that the UK can continue to move into more 'high-tech.' markets, including biotechnology. Japan has been the most prominent example of a country which has prospered by trawling discoveries from elsewhere and converting them into commercial products. It is now extremely anxious to build a strong 'science base' of its own in order to continue to prosper" (NEDC,1991:77).

The conclusion calls for increased spending on the science base but acknowledges that increased spending will not necessarily solve the problem. Moreover, the reference to Japan accepts that Japanese success in innovation was not based on a strong science base, but rather on improvement of existing techniques. Japan is thought by many to represent a new, more interactive, model of innovation.

The more interactive approach, takes into account knowledge acquired by workers, engineers and those working further upstream in the production process and feeds it back into basic science. It also allows for the existence

of tacit knowledge both at the science and production end of the spectrum; this knowledge can only be revealed over time and with intense communication. This more interactive model of innovation, was not represented among the British companies. At the level of developing technologies, MNC 1 does seem to pursue a more interactive strategy which stresses the importance of communication and different research cultures. However, given MNC 1's problems in marketing its products, the interaction between production, marketing and public relations were not so evident.

The chapter thus far has focused on the science-push end of the innovation spectrum and examined the impact of changes in the institutional environment on biotechnology innovation. It has looked at the impact of changing collaborative arrangements between universities and industry and new technology transfer mechanisms. While these changes between public and private spheres were designed with the intention of making science increasingly available for exploitation increased rates of innovation have been limited by institutional and organizational hurdles and the prevalence of linear model thinking. The following sections examine the markets into which agricultural and food biotechnology products feed and considers the impact of the market on innovation.

5.2. MARKETS AND INNOVATION.

5.2.1. AGRICULTURAL AND FOOD MARKETS AND AGRICULTURAL SUPPORT POLICIES.

Agricultural and food markets are, of course, very diverse and can only be talked about in general terms here. Nevertheless, there are some features of these markets and their structure which have influenced biotechnology innovation in important ways. The current flux in agricultural markets creates a climate of confusion and

insecurity for innovators. Not only are non-market developments directly related to biotechnology, such as patents and regulations, unclear, but concerns about the impact of changes in agricultural policies add to difficulties in predicting the shape of future markets. Additionally, this study's findings show that managers are concerned with identifying higher value added markets for biotechnology products, in order to recoup R&D costs. The combination of uncertainties in agricultural markets and the need to target products carefully in order make sufficient profit have, as shown in chapters 3 and 4 presented managers with a difficult task. Chapter 1 referred to Goodman et al's (1987) analysis of long term agricultural trends. They identify two principal strategies, both of which 'industrialize' agriculture, which are pursued in capitalist systems. Appropriationism is the term used to describe "the discontinuous but persistent undermining of discrete elements of the agricultural production process, their transformation into industrial activities, and their re-incorporation into agriculture as inputs" (Goodman et al,1987:2). Examples of this include, fertilizers, herbicides, hybrid seeds, machines. The authors say of this strategy,

> "In its fullest sense, appropriationism is constituted by the action of industrial capitals to reduce the importance of nature in rural production, and specifically as a force beyond their direction and control. This was achieved initially by relaxing the constraint of land as space via mechanization, and subsequently by the continuing struggle to transform the secrets of biological production into scientific knowledge and industrial property" (Goodman et al,1987:3).

Biotechnological examples include herbicide resistance, insect and disease resistance and tissue culture techniques. Some of the institutional changes which accompany technical transformations were discussed in the previous chapter. Substitutionism is a simpler concept and signifies the replacement of agricultural products with

industrial ones. For example, the replacement of natural fibres with synthetic fibres. This analysis provides an extremely useful way of classifying innovation and analyzing industry strategy. This section looks at the way in which longer term trends in agriculture and food industries interact with current market and industry structures.

5.2.2. THE SPECIFICITY OF AGRICULTURAL MARKETS AND INDUSTRY STRUCTURE.

Agricultural markets are, and have been throughout the 20th century, politically sensitive. They have been heavily manipulated to ensure politically desirable ends. Specifically, these ends have included incentives to increase food production, to increase earnings of farmers and to provide incentives for people to stay in rural locations rather than flooding urban centres. While agricultural support exists still in many forms, during the times of the 'green revolution' in the 1960s and 1970s the marketing environment differed from today's. At that time, government agricultural policies had the primary aim of increasing food production. A range of instruments including the provision of free advice on the use of new high-technology inputs, subsidies on such inputs and various forms of support for crop prices were employed to achieve the objective. The result was a virtually guaranteed market for any agrochemical industry product that would increase crop yields, and the launching of farming onto what has been described as 'the pesticide treadmill'. At the same time, public research institutes promoted competition.

"The results of this research have not only been more generally available for adoption, but also continuous infusion of advances has made it difficult to maintain high profits or inputs over the long term. In addition, the Extension Service has generally maintained extensive trial or test plot demonstrations of the effectiveness of a wide range of purchased inputs. This has tended to provide incentives for competition among input suppliers on the basis of product quality and performance" (Knutson et al,1983:242).

Appropriationist strategy, involving the development of agricultural inputs, thrived during this period.

The manipulation of agricultural markets over time has meant that the supply of food has in many cases, been greater than demand. Thus, while supports, combined with public research efforts, have in the past provided incentives for innovation, now there are system-wide disincentives to innovation. Price supports create an incentive for individual farmers to adopt new inputs and compete even though this may be inefficient in terms of the overall system. In the absence of reforms to agricultural policies, like the CAP, there would still be a market for products such as herbicide resistance or insect resistance plants, if they cut costs or increased profits to individual farmers. However, given current plans for the reform of agricultural policy in the EC, innovations which increase productivity are unlikely to be attractive to farmers. However, if reform is directed at making agriculture more competitive, some of the managers interviewed thought that even though food prices would decrease, there would be more demand for agricultural inputs which increased efficiency. The problem is whether the lower prices would be sufficient to recoup costs.

In areas where quotas have been introduced there is even less incentive to adopt innovations that enhance productivity. Previous chapters have noted the

unpopularity of such products as rBST which increases milk production. In 1984, the EC introduced production restrictions on diary products. Junne and Bijman explain the emergence and effect of this measure.

> "The rise in production in the past ten years has meant large surpluses of dairy products within the EEC. The surpluses cost the EEC large sums in intervention payments, storage costs and subsidies on sales. Exports on the world market offer little relief, since the EEC already accounts for 60 per cent of world trade in dairy products...A quota system was introduced, under which each Member State was assigned a maximum quota of milk to be produced. Such a system is of fundamental importance for the distribution of the effects of increased productivity. Under a quota system, productivity increases will force producers out of the market where the increases are the highest, whereas unbridled market forces would lead to a decline of producers in regions with the lowest productivity increases (Junne and Bijman,1989:77).

Again, while individual farmers still have incentive to lower costs, the case of rBST shows that in a situation of over production, agricultural innovation aimed at increasing output tends to be viewed as superfluous at best and counter-productive at worst. The combination of concerns about future profitability of agricultural markets and negative public opinion have both influenced managers' decision making about biotechnology, and in some instances have been identified as primary catalysts for companies' changing their innovation plans and identifying markets more carefully. While biotechnology has the potential to make agriculture more efficient, market and policy conditions make this a questionable strategy at present. Bye notes this contradiction between biotechnology's potential and existing market conditions, saying, "Advanced biotechnology can modify...market conditions. It will thus be contributing, in already saturated agricultural markets, to a swelling of stocks and a downgrading of price levels" (Bye,1989:70)

It is too early to say how agricultural reform might affect market conditions, but it is likely that future conditions could be more favorable to innovations which would lead to increased productivity than at present. In the EC the Common Agricultural Policy, is undergoing drastic revision in conjunction with The Uruguay round of the GATT talks. (FT, Sept,17,1991) It is likely that price support of many agricultural products will be reduced as will direct support to large farmers[5], leading to increased competition and maybe opening up of markets for new cost-cutting technologies. Additionally, plans to reform the Common Agricultural Policy indicate a preference for reducing the amount of land use for farming and increasing productivity. (FT,Sept 17,1991) Thus, in the future there could be more incentive on the systemic level for increased productivity in farming than there is presently.

Over the next few years, however, a number of pesticides will come off patent. One manager commented that it was hard to introduce new biotechnologies into a climate where chemical alternatives were "so damned cheap." This poses a challenge in terms of both substitutionist and appropriationist strategies. The findings in this study suggest that most firms have realized these difficulties and are targeting innovation much more carefully as a result. Work is certainly continuing on innovations related to large acreage crops, such as maize. As several managers pointed out, even if only small amounts of market share can be captured with innovations, it represents large

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5 An FT article summarizes the latest proposals to be put forward by the EC agricultural commissioner in the following way, "...the complex plan can be summarized as the deepest price cuts the EC has ever contemplated, combined with full compensation to small and medium-sized farmers, and scaled recompense to large farmers, contingent on the medium-to-large farms taking significant swathes of land out of production" (FT, September 17 1991).

sales. Additionally, with crops as significant as maize there is a 'defensive' pressure for companies to invest in R&D; the consequences of a competitor creating an important innovation is a significant incentive to innovate.

It may be, additionally, that agricultural inputs and markets will become increasingly segmented to incorporate a lower value, lower quality chemical based area and new higher value biotechnology based techniques. Certainly, some of the companies in this survey were interested in portraying biotechnology as a 'greener' technology or selling improved quality (for instance the MNC 2's 'improved tomatoes' in terms of appropriationist strategy and the high value meat substitute in terms of substitutionist strategy). In this way both appropriationist and substitutionist strategies for biotechnology which focus on improving quality, as well as quantity have been adopted.

Biotechnology will potentially decrease the need for certain agricultural products, by creating alternative products.

> "The introduction of biotechnology is...not always synonymous with the opening of new outlets for agriculture. It can lead on the contrary to the reduction or even the destruction of its traditional outlets, thanks to improvements in the techniques for exploiting the biomass. For example, the possibility of introducing new feedstuffs enriched with synthetic proteins considerably reduces the outlets for cereal crops. The recycling of milk whey in animal production has similar implications for vegetable-based proteins. The processing of effluent for food purposes decreases, rather than increases the use of agricultural products for food purposes" (Bye,1989:70).

Substitute products such as high fructose syrup (high fructose syrup is not a substitutionist product in the Goodman et al sense, as it is still derived from agricultural products) have had a dramatic impact on sugar

markets. In this case, the price of sugar was not a major influence on the viability of a substitute; the substitute would have large market appeal on diet and health grounds[6]. However, other substitute products are highly dependent on price fluctuations. Hacking (1986) provides an excellent analysis of the impact of price fluctuations on biotechnology derived substitute products. The success of fermentation ethanol is highly dependent on the relative price of oil, although in a number of cases, governments intervene to support the industry (Hacking, 1986:11). The future success of fermentation processes will rest on political commitment and the extent to which policies are directed toward creating alternatives to petroleum or using up agricultural surplus. Hacking says,

> "These policies can be criticized on the basis that they divert resources into propping up inefficient industries, or they may force manufacturers to pay more for indigenously produced feedstocks, which may make their products less competitive on world markets. They can, however, reduce foreign exchange losses and create employment. Perhaps more beneficially they can divert agricultural resources away from supplying already glutted world markets with prices below production costs in some instances. With many agricultural products, notably cereals and sugar, producing nations must either divert use into new applications or cut production. This may well be the greatest single influence in the development of large scale biotechnology. If the competitive threshold is lowered in this way, the subsequent process developments...can radically improve the economics" (Hacking,1986:288).

Current indications are that agriculture policy reform will be directed at reducing agricultural land and surplus, rather than the sort of policy changes Hacking is describing. In this case the outlook for the bulk end of

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6 Indeed because of the potentially devastating effects on sugar production, high fructose syrup based on imported maize was effectively blocked by EC sugar beet producers.

the market seems limited. If one looks at the strategies being adopted by large companies, it seems that they do not consider support for these kinds of projects likely and it was not a possibility that was discussed by managers.

Another example of the effect of relative prices has already been described in this study. The failure of the single cell protein project undertaken by MNC 2 was due to decreases in soya prices and increases in oil (used in the production process). As Hacking says many agricultural and food related biotechnology products have a high elasticity of demand.

> "In general the bulk products of biotechnology all show high elasticity of demand because they are challenged by other products or other methods of production. Single cell protein is perhaps the example with the highest elasticity because it is competing with other products, notably soy and fish meal which can substitute more or less directly" (Hacking,1986:21).

5.2.3. THE INDUSTRIALIZATION OF AGRICULTURE.

New biotechnology based products will not necessarily be incorporated into the existing parameters of the agricultural sector. Some products cross sectoral boundaries and biotechnology is likely to contribute to further diversification in agricultural and food markets. There is evidence of this trend in the study; pharmaceutical and agricultural markets have already begun to combine with the production of animals for pharmaceutical testing. Sheep are being used to produce a blood clotting agent. MNC 2's biological plastic, grown in a potato is another example. The attraction of this strategy is that agriculture products can be transformed into higher value output. The strategy is in addition, likely to be associated with increased collaboration (both between university and industry and between firms), as companies endeavour to incorporate new knowledge and

diversify. In Bye's view biotechnology will contribute to much more radical changes in technological paradigms. This is as much a function of the emerging structure of the industry and market as it is of technological properties. But it is a longer term, discontinuous process because of the need to develop new systems rather than just products.

The thrust of many agricultural support systems was increased food production and maintenance of smaller farms. However, the trajectory of the agricultural inputs sector has been towards ever higher levels of market concentration.

> "Concentration in purchased inputs used in agricultural production is generally high in absolute and relative terms. Concentration in inputs such as machinery, energy, seeds, credit, and chemicals, with the four largest firms frequently having over 50 percent market shares" (Knutson et al, 1983:241).

In the areas which relate to this thesis, seeds and chemicals, it would be wrong to attribute high levels of market concentration to agricultural support systems, nevertheless it is legitimate to surmise that market support systems (price supports and quotas) have provided stable environments which contributed to established firms' ability to move into consolidation of existing markets.

During the sixties and seventies, innovation in agricultural inputs mostly happened in large firms (Walsh, 1988:1-4). However, the combination of concerns about chemical inputs into agriculture on the one hand and opportunities offered by biotechnology on the other hand, seemed likely to open up space for new small firms to produce new kinds of agricultural inputs, based on biotechnology rather than chemicals. Added to this, institutional changes noted in the first part of the chapter seemed to offer new opportunities for smaller competitors. While some opportunities have been grasped

and developed by DBFs, smaller companies have found it hard to penetrate these markets. Although biotechnology, close to the science base and highly specialized, spawned new small firms, it also increased the tendency toward fewer and larger companies in the agricultural and food related sectors. The concentration of producers for agricultural markets began during the 1970s as competition intensified and has continued to the present day.[7] MNCs began to combine their agro-chemical work with plant breeding in new ways, breeding crops "under the chemical umbrella" (Tait et al:1990). Biotechnology, offered both opportunities to agro-chemical companies with the prospect of new products and a threat to the existing product base. For both of these reasons, MNCs continued to acquire plant breeding companies. From 1973 to 1988, major chemical and drug multinationals bought into more than 60 seed-producing companies (OECD,1988:28). Additionally, large food companies, eager to protect essential raw material invested in the new technology.

This confluence of, on the one hand, increased levels of vertical integration by large diversified MNCs, combined with, on the other hand, limited opportunities in many low value areas of agriculture and difficulties of protecting genetically engineered plants, influences biotechnology in important ways. Larger firms are in a position to use biotechnological knowledge in diverse ways and are thus able to redirect science towards more profitable outlets. Moreover DBFs have also used the common technological and scientific base to innovate in a number of areas. Some instances of this sort of activity have already been mentioned. Diversification activity occurs in a number of

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7 Henk Hobbelink notes, "Where 30 manufacturers were engaged in pesticides development in the mid-1970s in the United States, there are only a dozen today; the situation in Europe is similar. With a global market of some $20 billion, the top ten companies are now controlling a full 3/4 of it (Hobbelink,1991:43).

ways. First, the knowledge base can be put to work in different areas. For example, MNC 4's diversification into medical diagnostics, an area in which it had not previously been involved, on the basis of newly acquired knowledge. DBF 10's diversification into pharmaceuticals, from the core business of plant biotechnology is another instance of this. Second, there are instances of firms using agricultural innovations for other higher value output. MNC 2's use of its single cell protein innovation for a high value meat substitute, rather than animal feedstock would fall into this category. So would DBF 1's use of genetically engineered animals for pharmaceutical purposes rather than agricultural. As these firms travel further up the 'learning curve' it is likely that diversification will increase. Large MNCs in particular, are likely to use the same scientific and technological knowledge across a wide spectrum of activity.

Bye thinks that this will eventually lead to the redefinition of the functions of agriculture. The agricultural sector, as it becomes ever more industrialized, he contends, will become less specialized, feeding into a number of different sectors.

> "..one can predict a challenge to the organization of agriculture and food processing in a specialist sector. Upstream, the adoption of biotechnology leads to stronger links between engineering, chemicals and biology. The aim is less to produce in ever-increasing quantities than to produce at better cost, and with a view to downstream openings, which are no longer purely concerned with food, but also with energy and chemical applications. One no longer sees an increasingly specialised product derived from agriculture, undergoing successive transformations in order to become a specific food product. What must be envisaged, on the contrary, is that a complex product arising from agriculture or other biological or physical settings could be decomposed and then reconstituted to make a large new range of non-specific products" (Bye,1989:72).

Bye's argument is very similar to Goodman et al's. The technological trajectory will not be determined by technical factors, but a combination of technical and socio-economic factors. The concentration of production and increase of vertical integration by large producers is one of the most important of these factors. Pressure to 'free' agricultural markets, reduce the over production of food and reduce support to farmers gives companies an incentive to develop innovations which will cut the cost of agricultural production and to identify higher value markets for agricultural factors of production. As noted in other chapters, however, regulation, patent legislation and public opinion will also influence developments, as will the political and economic decisions taken by producers.

Several features of the interaction between innovation, markets and industry structure emerge from this discussion. Markets and prices clearly influence the direction and rate of innovation. However, markets and prices must be considered in conjunction with industry structure, with the broader institutional arrangements discussed in the first part of the chapter and viewed as social constructs and the products of policy decisions.

Given the historical tendency toward substitutionism and appropriationism noted by Goodman et al (1987) and corporations' ability to use biotechnology in a flexible way to maintain both strategies, it seems likely that further industrialization of agriculture, based on new biotechnology and older techniques will occur. In what form, however, and the extent to which they involve current biotechnology techniques, did not seem clear to many managers in this survey. The shape of the new industrialized agricultural system will depend on the complex interaction between institutions (public and private) and the markets. In the shorter term uncertainty

in agricultural markets and the cost of the technology seem, from findings presented in the case studies, to be delaying these innovations. Herbicide resistance, combining both chemical and biotechnological inputs is being pursued vigorously, most of companies in this study, with the exception of MNC 1, however, were not pursuing policies which would replace chemical with biotechnological inputs. Many managers in the study voiced concern about the competitiveness and effectiveness of biotechnology in relation to other technologies. The extent to which these transformations will take place, in the short term at least, will depend on comparative prices of inputs, and therefore on improvements in technology and, to some extent, on agricultural reform.

In the case of substitutionist strategies comparative prices will also play a role in the extent to which biotechnology is used to replace agricultural goods with industrial ones. Findings in this study, particularly the experience of MNC 2, in producing single cell proteins suggest that substitutionist innovations will take place in higher value areas initially where R&D costs can be recouped and where competition takes place in terms of quality rather than quantity. Regulations may also influence the extent to which substitutionist policies are adopted; high regulatory costs associated with the release of GMOs may encourage companies to look for alternatives to agriculture.

5.3. GENERAL CONCLUSIONS.

In both sections of this chapter, the emphasis has been on how factors associated with the changing nature of relevant institutions (both university/industry, industry structure and inter-firm relations), markets and policy have impacted on innovation. Organizational issues associated with the changes in university/industry and

inter-firm relationships and internal management issues related to technology transfer were not talked about extensively in interviews, particularly in the UK companies. When managers did express concern, it was usually related to the lack of funding for the science base. MNC 1, however, has seemingly given more thought and devoted more resources to the problem. The same is true of the impact of policy on markets. While managers talked about market opportunities and the lack of them, this was not often related to public policy issues or longer term trends in agriculture. The absence of analysis in the business world of the dynamics of market creation and broader issues of institutional change was also noted by Green (1991) in his study of healthcare markets and DBFs. The lack of analysis in both areas is perhaps indicative of a gap in management thinking which more generally affects the capacity for successful innovation in the UK.

On a more analytical level, this chapter, combined with previous detailed consideration of firms' strategies demonstrated the importance of viewing innovation as a process of change both within the firm and in the external environment. Amendola and Bruno characterize this approach in the following way:

> ...we must look at innovation as a process *in itself*: that is, not as the adjustment to something, but as the construction of something new and different. Its identification with an active learning process, and the stress on the crucial role that subjective factors play in this kind of process, does not mean that there are no regularities in it or, worse, that we can say nothing about it. It means that we must change the perspective from which we look at the problem" (Amendola and Bruno,1990:432).

This is an important point which relates back to the discussion in chapter 1 where I argued that it is necessary both to view innovation in the context in which it occurs, but also to recognize that firms in industrially advanced

societies play a primary role in creating new processes and products. The 'subjectivity' of firms, the importance of decisions made by leading actors, and the wide range of factors which contribute to decision making in those firms must be kept firmly in mind and balanced with the more structural and contextual influences.

CHAPTER 6. REGULATIONS, PATENTS, PUBLIC OPINION AND LEGITIMATION. THE POLITICS OF INNOVATION.

This chapter examines debates over regulations and patents, and relates them to political and social pressures. Chapters 3 and 4 showed that regulation, patent legislation and public opinion influence managers' decisions about biotechnology. Where regulatory issues have not been fully considered or where assessments have been inaccurate, companies have incurred significant penalties, as in the case of rBST. Regulation and public opinion and political pressure are intimately related; public opinion and political lobbying has an impact on the stringency of regulation and, on the other hand, risk regulation can be used to reassure people that biotechnology does not present a hazard. For this reason, companies engage in significant public relations efforts and some companies take public opinion directly into account in decisions about R&D. A recent survey, (EBIS,1991) however, shows that there is widespread distrust of industry in EC countries. In the light of this, the effectiveness of these public relations efforts is likely to be limited. In terms of patents, industry argues that R&D costs have to be institutionally recognized and that patents provide one way of ensuring that R&D costs can be recouped.

The point of this chapter is to demonstrate that innovation is a social and political process and integrally

linked to social trends and institutions of the political economy. The conclusion suggests three levels at which the issue of the politics and sociology of risk regulation and patents can be analyzed and thus makes connections between debates about risk regulation and patent legislation and the broader FRS concept of regulation. First, at the level of broad social and political trends relating to technology, widespread distrust of industry and the 'hardline' taken by industry representatives in terms of regulation of the technology and patent legislation, has not helped in defusing concern about biotechnology. The most intractable problem for industry is value-based opposition to the technology; while many interest-based arguments can be tackled on the grounds of economic efficiency, value-based arguments pose a more intractable problem for industry. Second, the exploitation of agriculture and natural resources have their own dynamics which have generated controversy over a long period of time. Third, the political activity of the firms involved, and their need to be legitimate as well as efficient producers, needs to be considered.

6.1. REGULATION.

6.1.1. BACKGROUND TO THE DEBATE OVER REGULATIONS.

Regulation of biotechnology could mark a new era in environmental risk regulation[8]. Regulation focuses on both contained use and on the release of Genetically Manipulated Organisms (GMOs). EC regulation of GMO release has provoked bitter argument between industry, commission directorates (directorates argue amongst themselves and with other protagonists) and pressure groups.

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[8] Regulations are primarily focused on the contained use and release of genetically manipulated organisms.

Tait explains the shift represented by the pro-active regulatory approach which emerged with biotechnology.

> "When the MNCs that are now operating in the biotechnology area were developing drugs and pesticides in the 1950s, 60s and 70s, the climate of risk regulation was entirely *reactive*. New products were assumed to be harmless until proved conclusively to be otherwise. Once a hazard had been identified, regulations were put in place to ensure that new products developed subsequently did not pose the same set of risks. No organized attempt was made to anticipate previously unforeseen hazards...In the case of biotechnology, an attempt has been made to learn from the mistakes of the past, to move beyond the previous reactive approach to risk regulation and to set up a system that is pro-active" (Tait,1990:15-16).

A pro-active approach signifies an attempt to identify problems in advance of the development and distribution of products. One member of the UK Advisory Committee on Releases to the Environment, which advises the British government on release and regulation, said when interviewed by a researcher, " We consider novel organisms guilty until proven innocent" (Levidow and Tait, 1991:5). Pressure for a more pro-active approach derives from recent experience with nuclear technology and chemical based agricultural inputs. Increased consciousness about health and environmental impact of technologies has added to pressure for more extensive and pro-active evaluation of risk. Tait identifies two major challenges to regulatory authorities which result from the new approach. First, prediction of risks and hazards is an extremely difficult task. "The human imagination can be boundlessly inventive; but we can fail to see outcomes that are, with hindsight, blatantly obvious" (Tait, 1990:17). Second, pro-active regulatory regimes necessarily complicate the politics of regulation. The pro-active approach requires public input into the regulatory process; the procedure is after all based on the perception of risk. Perceptions of risk,

indeed, the definition of risk, will depend in part on who is doing the perceiving. A person's or group's perception of risk will in turn be influenced by world view and political outlook and interests. Thus, the pressure for more pro-active approaches to regulation is linked to other political demands which call for more accountability and democracy in the process of technological innovation. These challenges for regulatory bodies also constitute new worries for industry. Industry is put in the position of having to fulfill contradictory aims; on the one hand it has to act in such a way as to maximize profits and on the other it is subject to demands for increasingly complex safety procedures and the worthiness of its aims and products. Brunsson makes the point that it is no longer sufficient for businesses to be efficient and commercially legitimate, they must also be legitimate in a broader normative sense (Brunsson,1989).

These rather abstract notions of re-active and pro-active regulation are intimately connected with a discussion about the merits of 'product-based' or 'process-based' regulatory regimes (Tait and Levidow, 1992). The terms have been used in different ways and this has led to confusion. The distinction sometimes means that there is a substantive disagreement; whether or not one agrees with product-based or process-based regulations depends, to some extent, on the perception of risk. Those who claim that the behaviour of genetically altered plants can be predicted by the behaviour of traditionally modified plants (plants which have been bred to express certain characteristics) tend to favor product based regulations. In effect, when used in this sense, product-based regulations signify a regression to reactive regulation. Supporters of process-based regulations express concerns about the sometimes unpredictable or damaging behaviour of GMOs when released into the field (RCEP,1989). Thus, supporters of process-based regulations tend to think that

release of GMOs represents new risks and the regulation based on the fact that final product is the result of genetic engineering is warranted. Tait, distinguishes between the two types of regulation:

> "A process-based approach can be defined as one where: (i) all products derived from the process of genetic manipulation, and designed to be released into the environment, are considered to have the potential to give rise to unique environmental hazards, not possessed by previous generations of products; and (ii) we need to devise new types of environmental oversight and regulation to ensure that any products giving rise to environmental hazards are excluded from further commercial development. A product-based approach is defined as one where: "(i) it is assumed that GMOs do not present any unique environmental hazards arising from the process by which they were developed; and (ii) any environmental hazards that they do possess can be regulated effectively by the systems set up to deal with foods, drugs and pesticides" (Tait, 1990:27).

However, in a number of cases individuals and groups who clearly favor process-based regulations as defined above, claim that they favor product-based regulation and the term has become confused (Tait and Levidow, 1992). The RCEP (1989) report is an example. A reason for this could be that industry is widely thought of as supporting product-based regulations. Perhaps the RCEP use of language constituted an attempt not to alienate industry from the outset, but rather to put forward suggestions which appear as compromise, thus allaying the public's fears, while giving industry a diplomatic victory. The RCEP position is that while regulations should be product-based, meaning that final products should be put forward for inspection rather than inspecting the techniques used in development, a special regulatory agency, with adequate knowledge should be formed to assess risks. Others, including industry representatives, stick to the 'line' that existing structure for regulating products are sufficient. However, even those managers who support a

strictly product-based approach agree that field trials should be monitored. In Britain, ACRE is the body which does this. Ultimately, however, countries within the EC will have to follow Commission directives with regard to regulation of biotechnology. The content of directives, however, remains controversial. At the heart of the debate is whether GMO products need to be regulated by a new structure at the commercial testing stage or whether existing structures will suffice.

6.1.2. THE REGULATORY REGIME.

In Britain, ACRE assesses proposed releases of GMOs on a case by case basis. Membership of the committee includes academic scientists, industrialists, representatives from such groups as environmental health officers and the Forestry Commission, the Green Alliance (appointed as an individual 'environmentalist') and assessors from relevant government departments (Levidow and Tait, 1991). ACRE is administered by the Health and Safety Executive, but is financed by the Department of the Environment (DoE), whose minister takes the final decision about release. The statutory framework for the regulation is Part VI of the Environmental Protection Act (Levidow and Tait, 1991:1). The committee has only approved one product thus far, a relatively uncontroversial bakers' yeast. Other releases are at the stage of small scale field trials.

There are four Community Directives which relate to future release of GMOs: - 90 (219) EEC, covering the contained use of GMOs in laboratories an industrial installations; - 90 (220) EEC, covering the deliberate release of GMOs for experimental and commercial development.; - 90 (679) EEC, covering worker protection (NEDC,1991:66). These three directives had to be implemented by member states by October 1991. A more

recent pesticides directive includes articles relating bio-pesticides and constitutes the fourth EC regulation relating to products of genetic engineering.

Because EC directives will be binding on all nations within the community, the fight over what constitutes appropriate regulation has largely taken place in this arena. Battles over regulations take place on a number of fronts. Controversy has centered around regulation of the deliberate release of GMOs, but has also included debates about whether biotechnology should be subjected to further assessments which would judge their socio-economic impact and the 'need' for products.

The basic controversies can be broken down into the following categories:

THE FOURTH HURDLE.

Advocates of the fourth hurdle proposed that certain GMOs should be subject to the same sort of assessment procedure which governs pharmaceutical products. The first three hurdles are safety, efficacy, and quality. The fourth would be "need". The definition of need has never been made clear, but it is generally accepted that what the fourth hurdle would require that products should constitute qualitative improvements or give quantitative benefits in areas where this was warranted. Many managers interviewed suspected that an informal 'fourth hurdle' already operates at the EC level and that obstacles being placed in the way of rBST were not based on worries about the product's impact on animals or humans, but on the 'need' criterion. These suspicions are not without basis. The decision to implement a moratorium on rBST in 1989 reflected concern about health and safety aspects, but also made explicit reference to socio-economic impact. EC Commissioner McSharry called for a study examining such matters which would be taken into consideration in any final decision

about a rBST license[9]. Indeed, the principle of non-scientific judgement being used to evaluate products has a non-biotechnological precedent; the agriculture commission has already banned certain steroids in meat solely on the basis of public opposition, even without scientific grounds for concern. (Roush,1991:36) Additionally, and of more direct relevance, a policy document outlining EC biotechnology strategy released in 1991, clearly stated that the commission would reserve the right to make judgements based on socio-economic impact of biotechnology products in controversial cases. (FT, 19 April, 1991)

Industry's response to suggestions of either an institutionalized or an ad-hoc fourth hurdle has been largely negative and is based on two principle objections: first, that a fourth hurdle on biotechnology products would be discriminatory; second that it would work against the whole dynamic of innovation. An interviewee claimed that had the motor car been subjected to a 'need' criterion at its inception it would not have been developed. His point is an interesting one; industry creates 'needs' for new products. Markets are created in a context; which arises from the intersection of culture, marketing, institutions and material resources in societies. The project of identifying needs is far more complicated than one might initially think and begs the question of who would decide what was needed. A third and related point is that the eventual usefulness of a product sometimes only becomes apparent after it has developed and then modified. One manager gave an example of a product which had originally been intended as a contraceptive. After it had been on the market for some time, it became apparent that it was more useful as an anti-cancer drug.

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[9] In Dec 1991, the Commission decided to extend the ban on rBST until 1993. MNC 1 was widely quoted accusing the commission of using the need criteria to judge the product (Independent on Sunday, 15 Dec, 1991).

As noted in chapter 4 some managers did not reject the idea of socio-economic assessment altogether. One manager of MNC 4 suggested that a European equivalent of the US OTA might be the solution to the problem; this would generate more information about technologies and cater to demands for increased democratic control, without giving a statutory basis to legislation. Another manager in MNC 2 also suggested that internal assessments might be made public. Industry representatives, particularly SAGB, have been clearly opposed to any form of study or assessment of socio-economic impact.

PROCESS vs. PRODUCT or VERTICAL vs. HORIZONTAL REGULATION.

The process vs. product debate has already been outlined. As the exact meanings of product-based and process-based became distorted, and the language became increasingly identified with polarized positions, two new terms evolved to distinguish between positions. The US system, whereby GMOs are assessed through existing structures set up to regulate non-biotechnology products, became commonly referred to a vertical system and the proposed European system which would involve a separate assessment body for GMOs, a horizontal one. Industry has taken a strong position in favor of US style vertical regulations, the Commission, or at least influential elements within the Commission favor a horizontal system. On the surface, the two systems seem to differ mainly in administrative terms. Indeed, Jan Brinkhorst, director general of the EC Environment Directorate, claims that this is the case. He says, "[The US authorities] have made special rules for GMO evaluation under existing laws - we made a new law. The result for industry is the same" (FT, Nov.29 1990).

While in certain respects this statement is true, it does not explain why, if the issue is purely an

administrative one, both industry and the supporters within the EC are so determined to get their way. Underneath the argument about administrative systems, there is a belief amongst supporters of 'horizontal' regulations that this new system will provide a more rigorous assessment of the impact of GMOs. Brinkhorst, links horizontal regulations with a pro-active approach. He says the EC approach is an attempt to act "before the event rather than afterwards (FT Nov, 29, 1990). Industry representatives claim that horizontal regulations will be more expensive, time consuming and complicated.

SAGB has lobbied the commission extensively over this issue[10]. While, as we have seen, each company has a different way of viewing and responding to regulations, SAGB has given industry a strong and unified voice in favor of product based regulation. It has had some success in promoting its views, but DG XI, the Environment Directorate remains strongly opposed.

Many managers interviewed complained that the most damaging aspect of regulation of biotechnology was the confusion and uncertainty about future stipulations. However, the EC directive governing release, as noted, was greeted with widespread dissatisfaction by industry. Industry accused the Commission of "political hostility" toward the technology (FT, Nov 29, 1990) and produced figures purporting to show that, largely as a result of a damaging regulatory environment, new investment in biotechnology in the EC had dried up. (SAGB,1991) Brinkhorst responded that EC regulation "cannot be made the scapegoat for the somewhat slower development of

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10 National biotechnology industry associations are also active in promoting the technology and there are other EC initiatives, such as The European Biotechnology Coordination Group, which aim to communicate industry's views to the Commission. Nevertheless, SAGB, since its inception, has become the most prominent.

biotechnology in Europe" (FT, 29 Nov 1990). Additionally, he claimed that a comparison of the number of field tests being undertaken in the US, Europe and Japan showed that regulation was not having an adverse impact on innovation. The approximate figures up to mid-1990 were US 115, EC 110, and Japan 1.

A policy paper, introduced in April of 1991 also engendered negative reaction from most parties. The policy paper "promised to limit the regulatory burden on Europe's biotechnology industry and to set up a committee to tackle the ethical problems of genetic, environmental and human embryo research" (FT, 19 April, 1991). One Green MEP commented that "It's as though the biotech industry had given the Commission its wish-list, and the Commission turned it into their basic position paper" (FT, 19 April, 1991). On the other hand industry representatives complained "that the Commission could still discriminate against biotechnology products by subjecting them to an extra level of testing and regulation, irrespective of the type of product" (FT, 19 Nov, 1991). This 'extra level' of testing refers to an assessment of the environmental impact of GMOs regardless of the final product in which they are embodied. Industry was also annoyed about the fact that the document implied that the EC would retain the prerogative to take 'political' decisions about biotechnology when controversy arose about adverse socio-economic impact of products. rBST was mentioned explicitly.

The Commission's directive on pesticides, devised largely by the Agriculture Directorate, on the other hand, was welcomed by industry. In seeming contradiction to the former directive, which implemented horizontal regulatory principles, the pesticides directive stipulated that biopesticides should be assessed through the same administrative channels as other pesticides.

6.1.3. REGULATION, LEGITIMATION AND PUBLIC OPINION.

Public opinion about biotechnology, or more precisely genetic engineering constitutes a significant worry for industry. Opinion polls show that there is concern about the impact of biotechnology, particularly in terms of food and agricultural applications (Tait, 1990). At the same time, the polls show a high level of ignorance about what biotechnology actually is. However, the belief expressed by many managers that education about the technology will solve the problem may also be mistaken.

Tait distinguishes between the NIMBY syndrome (not in my backyard) and the NIABY syndrome (not in anybody's backyard). She points out that many opinion polls only give superficial data about people's perceptions and do not "indicate the extent to which opinions are motivated by concern for the interests of protagonists or by ethical and value-based considerations" (Tait, 1990:34). This distinction is important to understand, she says, because it will affect the effectiveness of efforts to resolve the problem.

> "...a conflict of interest can sometimes be resolved simply by giving more or better information to change the public understanding of the potential impact on their interests. Where there is a genuine divergence of interests, the various parties can bargain with one another until a satisfactory settlement is reached. Conflicts of value, on the other hand, can be exacerbated by both tactics. Protagonists in a value conflict will only accept information that is in accordance with their beliefs; everything else will be treated as propaganda and its source discredited. Attempts at bargaining to reach a settlement will be treated as bribery, trading principles for cash - again leading to a worsening of the conflict. The traditional adage "I cannot hear a word you say because what you are shouts so loudly in my ears", epitomizes this situation" (Tait, 1990:36).

Tait notes that in any group of people, concern will be based on a mixture of value and interest considerations.

Different biotechnology products create different levels of opposition and give rise to different concerns. In the case of rBST, opposition is both interest-based (small farmers) and value-based (animal welfare groups, amongst others). Plant biotechnology and biopesticides are also likely to give rise to both types of concern. It is unlikely, as Tait points out, that value conflicts can be fully resolved by increased information, especially if parties with interests at stake are providing the information.

The resolution of concerns about biotechnology by means of increased information appears even more unlikely in light of a recent survey which indicated high levels of distrust of industry. The detailed survey, called the Eurobarometer was undertaken by the EC, involved interviews with 12,800 people in member states (EBIS, 1991). Only about 50% of participants thought that biotechnology would improve their lives. 7% fear that it would 'make things worse'. When asked about genetic engineering specifically, 47% of interviewees thought that it would improve their lives and 15% thought it would make things worse. The most worrying part of the survey, however, must have been the response to questions about whom the public trusts to tell them the truth about biotechnology. The following figures are percentages of interviewees mentioning the various possible sources:

1. Environmental organizations 52.6%
2. Consumer organizations 52.4%
3. School or university 37.2%
4. Animal welfare groups 29.1%
5. Public authorities 20.4%
6. Religious organizations 9.7%
7. Industry 6.0%
8. Trade Unions 5.3%
9. Political Organizations 4.9%

(EBIS, 1991:18).

Given this situation and the high degree of value-based opposition to biotechnology, a 'resolution' of bitter arguments about regulatory regimes would probably require evidence of change in industry values. While industry has increasingly tried to portray itself as 'green' and has claimed that biotechnology can create safer agricultural practice, its stance on regulation undermines faith in this conversion. Public relations efforts which attempt to portray biotechnology as 'green' and 'modern' will probably not suffice if industry is seen to oppose regulation and develops unpopular products such as rBST. Some managers interviewed in this study tended to belittle the concerns not only of environmental groups, but also of EC regulators.

Roush (1991) analyzes the struggle over the acceptability and regulation of biotechnology in terms of this wider framework. Biotechnology, he says has become the focus for new types of social activism. Tracing the debate over rBST, he highlights the level of distrust that exists between public interest groups and industry. There is also a feeling that regulatory authorities are not to be trusted. "Allegations of overly close cooperation between the chemical companies and the FDA have surfaced throughout this controversy" (Roush,1991:32). The key to understanding the dynamics of the battle of rBST, he suggests, lies not only in the specifics of the technology, and worries over impact on human and animal health, but over the broader question of who should control technological development and who can be trusted to innovate responsibly. Fears about rBST tapped into a strong current of mistrust about industry, governments and universities interests in technological development. Anti rBST activists are keen that the public should have more say, not in regulation of technology, but in setting R&D

priorities. Thus, while the immediate goal is to stop use of rBST, activism "...is fueled by an underlying belief in the public's right to participate in technological decision making" (Roush,1991:36).

6.1.4. INDUSTRY STRATEGY AND LEGITIMATION.

Interviews with industry managers suggested that confusion over regulation and worries about 'inappropriate' regulations have, in the case of small firms in particular, had a pronounced influence on strategic and R&D decisions about biotechnology. Small firms, inexperienced in dealing with regulations and, in many cases, desperate to rectify cash flow problems, viewed regulations as a constraint on production. Regulations constituted an added incentive to license, or develop intermediates in order to avoid lengthy regulatory procedures. However, only in decisions about final drug production was regulation cited as the major constraint; in general it was viewed as a constraint in the context of other problems relating to lack of finance and management expertise. In all but one of the DBFs involved in plant and agricultural biotechnology managers viewed the new EC regulatory regime as something which could be lived with. Moreover, three managers in DBFs stressed that regulations offered opportunities as well as constraints; regulations could be viewed as setting standards which firms could aim for[11].

In the case of large firms, who have naturally been in a much better position to lobby for favourable regulatory conditions, the concrete impact of regulation was hard to detect. While managers spoke a great deal about regulation, it was usually in the context of future consequences and not on previous impact. In the case of

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11 This conceptualization of regulation has gained currency recently and is explained and advocated by Porter (1990).

MNC 4, regulation was cited as one the factors which contributed to the company's decision to pursue a more cautious approach to biotechnology. However, in this case, public opinion was an equally important factor in influencing innovation. The intimate connection between regulation and public opinion complicates the discussion of impact of regulation and industry strategy.

If the connection between regulation and public opinion is kept in mind, the argument about which set of regulations should be implemented becomes more comprehensible. The immediate questions of impact of regulations and comparative costs are not the only, or perhaps even primary question for large companies. Large firms are perhaps more concerned that biotechnology be widely conceived of as nothing different from older techniques. Thus, the administrative question of whether biotechnology is assessed by means of existing or new structures becomes significant. Thus, while managers in different companies had varied opinions about the way in which biotechnology should be promoted, and even about the risks involved, they were keen to have regulatory authorities acknowledge that genetic engineering poses no special risks.

Given the lack of concrete evidence that a 'horizontal' regulatory regime would add significant cost or complexity to the process of licensing products, industry's claims in this regard should be treated with skepticism. However, if the principle of more pro-active regulation, were adopted in the case of biotechnology, it might eventually become the norm, rather than the exception. This could have far reaching implications for industry and could be a second reason that industry representatives of large MNCs are lobbying hard for more reactive types of legislation. The extension of the democratic principle involved in pro-active regulation does

not appeal to industry. Additionally, industry is very keen that regulation should not involve any socio-economic assessment, despite the fact that large companies do internal assessments of this kind. Companies appear to favor keeping the guiding economic hand invisible, rather than visible.

The battle over appropriate regulation should be considered in light of industry's overall motivations for adopting the technology. The industry viewed biotechnology as a way of increasing, not maintaining profitability. Disappointments resulting from limited possibilities offered by seeds and agricultural markets have perhaps translated into calls for less regulation. Whereas the pharmaceutical market has high enough profit margins to withstand high regulatory costs, agricultural markets now offer less lucrative opportunities. This, in combination with longer lead times than expected and higher costs of R&D, make industry keener to cut regulatory costs.

The problems which industry has encountered with respect to regulations can be seen in terms of the conflicting demands to which it has to respond. On the one hand, as shown in the company case studies, industry has 'hyped' the technology in order to gain support from shareholders, acquire money from investors and gain political support and assure public enthusiasm. On the other hand, industry has tried to argue that genetic engineering does not represent anything new in terms of potential risk. It has done this in order to argue for lower levels of regulation. However, given its own claims for the power of the technology and the complicated politics surrounding biotechnology, industry insistence that 'vertical regulation' will suffice as an evaluative procedure, has to some extent backfired, causing public concern. Given high levels of distrust of industry and politicians and, conversely, faith in environmental

organizations, further dispute over the technology seems likely. Moreover, as concern about biotechnology has grown, industry seems to have become more, not less, unwilling to compromise about regulatory issues. For example, one manager told me in an interview that Greenpeace was an organization that his company could work with and seemed confident that understanding could be reached. At the end of the study, when I sent interview notes back to managers in order that they could check them, the manager wrote back to say that he had changed his mind about Greenpeace and now thought of them as a 'closed mind' organization.

Many environmental organizations have expressed grave concern about biotechnology's impact on the environment. In Britain, a group called The Genetics Forum has been formed specifically to monitor developments in biotechnology. Recently, Greenpeace opposed all further developments in genetic engineering of plants and animals.

In the US, recent attempts to further deregulate biotechnology have caused "a storm of criticism" (New Scientist, 25 May, 1991). The new proposals, drafted by the White House Council on Competitiveness, hold that GMOs "shall not be subject to federal oversight" unless there is strong evidence that they present "unreasonable" risks. Even where possible risks are established, federal regulators should not get involved if those risks can be "addressed by other mechanisms" such as the recovery of civil damages through the legal system (New Scientist, May 25, 1991).

The proposal, which clearly marks a complete reversal to reactive regulation, was greeted with outrage from environmental groups and the Environmental Protection Agency. Even industry representatives expressed concern. The New Scientist reporter notes, "Earlier versions of the government's regulations had defined a set of genetically

altered organisms that would not require approval" (New Scientist, May 25, 1991). This exempted organisms that could be produced by traditional plant breeding methods or those that contained new genetic material which causes no change in the original organism's function. "The new draft dropped all mention of these exemptions, instead proposing that regulators ignore the process by which an organism is produced." The article goes on to quote an ICI Americas spokesperson, who said that the new approach risked regulatory chaos and that it could mean going back to square one (New Scientist, May,25, 1991).

The SAGB document, (SAGB,1991) on the other hand, makes constant reference to the need to compete with the US and therefore, have similar regulatory regimes. A recent NEDC report makes the same point. (NEDC, 1991). Yet, if regulations are widely perceived as insufficient in the US, and concerns in the EC are not adequately addressed, this line of argument could have serious unintended consequences for industry.

The context of heightened awareness of environmental and health issues and ethical concerns about genetic engineering could well combine with a more general crisis of legitimation in industry and political institutions, and demands for and extension of control over technology, to make life harder, rather than easier for industry. Many managers interviewed in this survey understood the demand to increase legitimation and confidence by implementing regulations which are perceived as rigorous. Some even agreed that socio-economic assessments might be appropriate. Yet, the 'official line' represents a very different attitude and one that calls for minimum regulations. The new pesticides directive which represents a victory for industry has already given rise to increasing concern amongst Greens and their European Parliament representatives. According to this directive,

the decision to license a pesticide will be made by a committee of experts in Brussels. The new directive does not include specific rules for GMOs and although the agriculture directive has promised to add new criteria within two years, Greens worry that the rules will not provide the same protection as they will be applied directly by a committee whose interests lie with agribusiness. The new committee will "bypass the expertise and concerns of national environment ministries" (New Scientist, May 25, 1991). Industry's intransigent position over regulation fuels public suspicions. Their claim that biotechnology represents a greener technology and one that will contribute to a more 'sustainable' agriculture could be as misleading and therefore likely to contribute to both interest based and value based opposition. Short term gain from reduced regulatory hurdles may well be outweighed by longer term, sustained pressure from environmental groups, consumer groups, sympathetic politicians and other pressure groups and may, in the end, prove more costly to industry.

6.2. PATENTS.

6.2.1. PATENT LEGISLATION.

The question about whether life forms should be patentable has proved equally as controversial as risk regulation, although the issues have a lower profile. An early landmark in the debate over patenting life was a US court case Diamond v. Chakrabarty which established that the "inventor of a new micro-organism could not be denied a patent solely because the invention was alive" (Orsenigo, 1989:46). In the US, in 1985 full patent rights were extended to plants and in 1987 to animals. However, biotechnology patents are the subject of considerable litigation. In the EC, the question of what should be patentable remains extremely contentious. In the area of

plant breeding, the granting of patents extend the traditional protection given to plant breeders through plant breeders rights. In some sense the granting of patents can be seen as a logical next step in the commercialization of agriculture, a legal and institutional equivalent to recent advances in genetically engineered hybridization techniques. As such, patents would extend capital's control over agriculture; 'industrialization' of agriculture, to use Goodman's (1987) terminology would be taken to another stage by allowing patents on seeds. The issue is, however, technically complex and politically explosive.

The EC has been relatively slow in drawing up patent legislation and the issue remains controversial. It now seems, likely, however, that patents will be granted on animals and on certain genetic innovations in plants (FT, May 29, 1991 and Bio/Technology, July, 1991) but the institutional framework for the protection of genetically altered living things remains contentious and unstable. The following sections discuss some aspects of the debate about patenting life.

6.2.2. PATENTS ON LIFE.

A patent is,

> "...a right, granted to an inventor by the state to exclude anyone but the inventor from commercially exploiting the invention, except under license from the inventor. Such licenses normally demand the payment of a royalty fee. In return for this right, the inventor must provide a full description of the invention (Genetics Forum,1991:1).

For a process or product to be granted a patent it must be: 1) novel, that is produced by human intervention and suitable for industrial application; 2) unobvious in that it requires some specialized innovation and applied skill; and 3) it must be an invention, rather than a

discovery. This last clause precludes the products of nature from being patentable and is at the centre of many of the legal and technical wrangles over the patenting of biotechnology products.

In 1985, Harvard University submitted an application for a patent on the 'Onco-Mouse', a mouse genetically altered to develop cancer. The European Patent Office originally rejected the application under Articles 53 and 83 of the European Patent Convention (EPC) (Bio/Technology, July 1991). Under this convention, animal 'varieties' should not be granted patents and due to confusion over the definition of 'varieties', previously taken to mean natural differentiation, the patent was denied. Another objection was that the patent claim, which covered all non-human applications was too broad given that only one genetically altered animal was put forward. The application then went to an Appeals Board, who reversed the decision. The reversal of the decision, granting a patent for the Onco-Mouse established important guide-lines for future patent applications. (Bio/Technology,1991:619) One of the key principles established is that animal varieties can be patented, if they are the products of a "microbiological process" (Bio/Technology,1991:620). Another clarification which will have far reaching applications relates to the judgement that broad patent claims which include all applications of specific genetic transformations was viewed favorably (Bio/Technology,1991:620). Using the onco-mouse as an example, this means that the stretch of DNA is protected in any application. The Appeal Board reserved the right for the Examining Division to consider the moral implications and possible resulting animal suffering on a case by case basis.

While the onco-mouse was granted a patent, the more general issue of biotechnology patents remains unclear, an EC draft directive leaves many questions unanswered. The

situation regarding plant patents is made more complicated by previous legislation and agreements on protection of new plant varieties. Intellectual property on new crops is currently protected by an international convention called UPOV (the International Union for the Protection of New Varieties of Plants). The convention dates from 1961 and has been signed by 18 countries. UPOV gave legal status to Plant Breeders Rights (PBRs). PBR encouraged the privatization of plant breeding, setting the stage for the first wave of MNC investment in seeds companies (Hobbelink,1991:105 and Kloppenburg,1988). As chemical and food companies increased levels of investment in biotechnology R&D and the focus of that investment became living organisms rather than chemical in-puts, demands have been made to extend protection and allow for the application of industrial patents on plants. The UPOV convention has recently revised its provisions in order that patent protection and PBRs will not overlap. PBRs will continue to apply to vegetal and plant varieties; patents could then cover specific parts of the plants. This is congruent with patenting of stretches of DNA, rather than specific applications. The new convention removed the prohibition on double protection of plants; genetically manipulated varieties could be covered by both PBR and patent protection.

A major difference between patents and PBRs is the scope of protection granted.

"The convention is designed to provide some incentive for the creation of new plants, but at the same time to allow free access to plant material. "Plant breeders' rights" protect new plant "varieties", which the convention defines as new plants that are distinct from other species, homogeneous and stable from generation to generation. The convention allows only the breeder of the new variety to sell any resulting crops although, under the "breeders' exemption", other breeders may experiment with the protected variety. Under the "farmers' exemption", farmers may store and re-sow seed taken from the initial protected crop. In contrast, under the terms of a patent, farmers and plant breeders must ask permission to use a protected plant or animal, and pay a royalty on every subsequent generation they produce. Also, patented plants or seed will not automatically become available for at least three years after a patent is granted" (New Scientist, 12 January,1991:59).

A proposed EC directive puts forward the view that all genetically engineered plants and animals should be patentable. Indeed, a number of plant patents have been granted already in the EC, although not as many as in the US, where patents have been regularly granted since 1985[12]. But technical problems and political opposition persist. One of the principal problems involved is judging the level of invention in genetically engineered products. One of the criteria for granting of patents is that the product must be a new invention, not a discovery and it must not be obvious.

"Lawyers will have to decide whether scientists, in making use of stretches of DNA, have invented something and are therefore entitled to patent rights, or whether they have merely discovered a sequence of genes and have no such entitlement" (New Scientist, 12 January, 1991:57).

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12 In 1985, The United States Board of Patent Appeals and Interferences granted Kenneth Hibberd and his co-applicants a patent on the tissue, culture, seed and whole plant of a corn line selected from tissue culture setting a precedent for future decisions about patenting plants. (Kloppenburg,1988:263)

Contradictory legal precedents in the US portray the complexity of the issue. In 1989, the Court of Appeal held that human tissue plasminogen activator (an enzyme that dissolves clots in blood vessels, produced by Genentech using rDNA technology) was not patentable. In the judgement of two intellectual property lawyers, "The ruling seems to suggest that where there are many research teams working towards the same goal, any products generated using recombinant DNA technology are unlikely to satisfy the statutory tests of novelty and obviousness (New Scientist, 27 July, 1991:8). However, the University of California was granted a patent for a process known as "immortalizing the cell line', whereby white blood cells, found in the spleen were persuaded to reproduce indefinitely. A number of other patents on human cells have also been granted in the US, " on the grounds that they would not exist but for the intervention of the "inventor" who extracted and manipulated them to reproduce indefinitely" (New Scientist, 12 January,1991:57).

The situation in the EC is unclear. The European Patent Convention maintains that essentially biological processes cannot be patented. The EC draft proposal classes all products of genetic engineering as not essentially biological and therefore, patentable. "This means that the tiniest and most standard piece of genetic engineering could render a process patentable, even if the bulk of that process takes place by straightforward biological means" (New Scientist, 12 January, 1991:58). This clashes with the European Patents Office guide-lines which state that human intervention must play a "significant part". The draft proposal would allow "even the process of purifying a natural substance to identify its genetic sequence constitutes human intervention and so renders the product patentable - even the sequence is unchanged" (New Scientist, 12 January, 1991:58). This

interpretation of significant human intervention is disputed by many[13].

The directive classes any manipulation of a plant or animal as "microbiological", and therefore patentable. This definition runs in potential contradiction to the scientific definition of microbiology as the study of single-celled organisms, such as yeasts and bacteria. Hobbelink calls this "redefining biology to fit patent law" (Hobbelink,191:106). This clash over the definition of natural and the extent to which genetic manipulation is a product of human intervention is at the heart of the dispute over patents. Industry's main argument is that if huge R&D costs are incurred, patents are necessary in order to ensure that sufficient profits can be made to justify further innovation[14].

Another major technical difficulty involves enforcing patent protection. Because plants and animals reproduce themselves, and therefore their distribution and sale is difficult to track and patents are hard to enforce. Enforcing patents in the case of offspring of a genetically manipulated cow would mean monitoring the breeding of the cow. The same principle applies in the case of plants. One of the small companies involved in this study, recognizing the problem, developed a genetic technique for hybridization, which would go some way to resolving the problem. This would mean, however, that plants would conceivably incorporate various different patented parts.

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[13] David King, a microbiologist and head of The Genetics Forum, for example holds that "...purification involves only standard cloning techniques, which are the staple diet of biotechnology, and is not enough on its own to constitute significant human intervention" (New Scientist, 12 January,1991:58).

[14] It is not clear, however, whether industry will benefit if broad patents are granted to university researchers, who will then be able to license their strips of DNA and demand royalty payments.

Multi-patented plants would be significantly more expensive and it seems unlikely that the economics of plant breeding and farming would allow for this.

Socio-economic factors create difficulties for patents on animals and plants. Interest-based opposition comes in particular from farmers who fear that patents would significantly increase costs. Farmers would have to pay royalties on every generation of plants and livestock they buy and reproduce. Patented proprietary products would be more expensive. Opponents of patents also worry about increased farmer dependence on MNCs (Hobbelink,1991:109). Patents could also have a negative impact on independent breeders.

> "Breeders will no longer have free access to germplasm for developing new varieties of plants and animals. Genetic resources, including genes, cell lines, protoplasts and even characteristics (like 'high yield'), will become the exclusive property of top biotechnology firms. Licences will have to be obtained and royalties paid for, in order for breeders to be able to incorporate patented genes and characteristics into new crop and animal varieties. Most independent breeders will go out of business. As a result, the only innovation in the breeding sector will be found in the legal departments of large corporations where patent lawyers will dictate the direction of biological research" (Hobbelink,1991:109).

The findings of this study suggest that Hobbelink's conclusions are not exaggerated. In the case of MNC 4, the decision to invest in biotechnology largely rested on manager's fears that other companies' patented products would give them competitive advantage. MNC 4's R&D was to some extent directed by the objective of developing patentable products which could then be used in swop situations; MNC 4 would offer to license its product in return for the same agreement from other countries. MNC 2 is adamant that in order for R&D to continue on plant biotechnology, patent protection must be granted. The implication, of course, is that research will be done in

areas where patents are obtainable. While Hobbelink argues that patents will increase market concentration and work against the smaller producer, managers of DBFs tended to see patent protection as vital to their efforts. One CEO of a DBF concentrating on plant biotechnology and agricultural inputs stated in response inquiries about where R&D projects are originated stated the following;

> "We've had instances where we've had the patent lawyers go in and speak to people. And the patent lawyers, in the conversation, say, 'what kind of thing are you doing that you think potentially could be patented...and we've had ideas come from that there."

Patents were far from being the only consideration in determining the direction of R&D, but they were mentioned in a number of cases as one of the more important influences. In the case of the Belgium based DBF, patents also influenced R&D decisions but with a very different outcome; the difficulties of securing patent protection led the company to develop a genetic hybridization technique with which new inventions and varieties could be protected without resorting to patents. Two papers written for an assessment of the 1980 Spinks report, called Biotechnology: Spinks Eight Years On, call attention to the impact of patents on innovation. A paper on plant biotechnology and agriculture points out that winning "major patent positions" is an important objective of innovators. (Flavell, 1989:88). In a paper on animal biotechnology, on the other hand, Cross includes the following point in a section on "potential hazards to animal biotechnology" (Cross,1989:133):

> "-Intellectual property constraints. The negotiation of sustainable contracts between research workers and commercial developers can be lengthy and delicate. Exclusivity and confidentiality terms expected by companies cane be detrimental to scientific progress. Pursuit of knowledge and pursuit of profit are not always compatible" (Cross, 1989:133).

Cross alludes to concerns held by many that patents taken out on biotechnology R&D will hinder the practice of science.

There are concerns about the wider impact of patents on market structure, the environment and developing countries. While many managers claim that patents will lead to further innovation, opponents claim that decreased competition and broad patents which cover all applications of a particular genetically manipulated micro-organism, will lead to less innovation.

The argument about increased market concentration is linked to another concern about biodiversity. Biodiversity became a major concern during the late 1980s. Dangers involved in loss of genetic diversity constitute a serious threat. A high profile report, written by representatives of NGOs, private industry and the UN stated "We can hardly imagine a greater threat to the future well-being of the people of the world than the loss of genetic variability of plants" (Keystone International Dialogue Series, quoted in King,1991:1). The worry is that biodiversity, (already at risk from environmentally damaging development projects, destruction of rainforests, etc.) will suffer erosion as fewer producers gain greater control and products become more homogenized.

Most of the world's genetic resources come from developing countries. Thus, efforts to conserve genetic diversity are focused on countries in developing countries in The South. A conference to be held in Brazil in 1992, under the auspices of the UN will focus on biodiversity as a major issue. Numerous issues are involved, which would require an entire Ph.D. to explicate and discuss them[15].

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15 Contradictions exist, for example between GATT efforts to implement international patent and conservation of biodiversity.

The issues involve both interest-based and value-based concerns; one of the principal arguments against granting patents on plants is that while essential germplasm, derived mostly from developing countries, is claimed as The Common Heritage of Humankind and is free, costly propriety products would have to bought back by countries in the South[16].

Ethical considerations are also an important part of the debate. A document put out by Patent Concern, a coalition of pressure groups, formed by the Genetics Forum, summarizes some of the issues in the following way,

> "The patenting of animals clearly raises ethical concerns which are distinct from the more general question about whether genetic engineering itself is unethical. Critics of patenting have objected to the 'ownership of life', which they feel would debase it to the status of a mere commodity...Patenting of life forms...rests upon the claim that they are our 'invention'. Traditionally, living things have been viewed as not patentable, since they are products of nature, rather inventions. Viewing animals as our invention may weaken ethical constraints in our treatment of them, since they are not thought of as independent creatures, but as totally dependent on us. In the context of a society which, over the last few centuries, has developed an increasingly exploitative and arrogant attitude towards the rest of nature, patenting appears to be yet another twist in the spiral of exploitation" (Patent Concern, 1991:3).

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16 Strong arguments are now made that germplasm from developing countries should be paid for. Jack Kloppenburg and Daniel Kleinman have coined the phrase 'Seed wars' to describe these battle. They suggest that all breeding lines should be considered common heritage. This, they recognize is politically unfeasible and therefore argue that germplasm should be considered as national sovereignty. They suggest, however, that countries in the South should bargain with their genetic resources, not just for cash, but for technology transfer and training in the areas of plant breeding and genetic conservation. These suggestions have gained currency and are being debated by various UN agencies and international agencies in the run up to the 1992 conference.(See J. Kloppenburg and D. Kleinman, 1987)

Religious groups have also expressed concern over the issue of patents for genetic manipulations. The patenting of human genes raises particular issues. Patents have already been issued on human cells in the US, "...on the basis that they would not exist but for the intervention of the "inventor", who extracted and manipulated them to reproduce indefinitely" (New Scientist, 12 January, 1991:57)[17]. The US Patent Office has said that it will not allow the patenting of human beings; patenting of humans would contravene anti- slavery legislation. It has not made clear, however, how it intends to distinguish between human cells and human beings. The EC draft directive does not prohibit the patenting of human cells or beings. As the human genome project, an international effort to work out the functions of all genes in humans, progresses, and patent applications begin to be filed by researchers, concern about the issue seems likely to escalate.

The EC, recognizing that the ethical quandary over biotechnology and over patenting, and recognizing the lack of trust between parties involved in the debate and between the general public and industry, decided to create an advisory body, "capable of dealing with ethical issues where they arise in the course of Community activities", in an effort to defuse the issue. In light of the Eurobarometer poll mentioned earlier, however, the effectiveness of this body to "[facilitate the acceptance of [biotechnology's] benefits" (EBIS, 1991:2) remains to be seen.

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17 A landmark court judgement with regards to this matter was the State Supreme Court of California's ruling in the Moore Vs. University of California case which gave the university patent rights over cells extracted from Moore's spleen.

6.2.3. INDUSTRY STRATEGY AND IMPACT OF PATENT LEGISLATION.

Industry has been less vocal in its support of patents for biotechnologically derived agricultural and food products. This could be because the issues are complex and less amenable to public relations campaigns which play down self interest and emphasize public good. The argument for patents necessarily revolves around increased remuneration for developers of the technology.

Industry makes the case that patents will ensure innovation. If patents are not granted, there will be insufficient incentive to undertake expensive R&D. "Companies claim that they would not bother to spend money on research without guaranteeing financial returns for innovation" (New Scientist, 12 January, 1991:59). Opponents claim that this is untrue. "They note that many biotechnology companies have conducted research on genetic modification for at least 10 years, before it was clear that they would gain patents on their work" (New Scientist, 12 January, 1991:59).

There is evidence that patents are also becoming less attractive as a means of protecting R&D. As the speed of innovation becomes ever faster, firms find that secrecy works better than patents as a means of protection; patent protection demands that the innovation be described and key information made public which perhaps gives competitors a better chance of making improvements. Additionally, in the area of biotechnology, where the patent legislation has been tenuous and where firm precedents are few and far between there is more incentive to opt for secrecy rather than patents (Orsenigo, 1989). However, while firms may be using secrecy to protect R&D, patents protect innovations when they have been marketed and carve out a company's turf in a way that secrecy cannot. Thus, patent protection, as many managers in this study confirmed, is particularly

important to companies when they are dealing with a radically new technology (Orsenigo, 1989).

While patents may play a very important role in rewarding companies for initial investment, as an industry moves through the product cycle, there is evidence that they become less important as incentives to innovate. Cumulative knowledge and place in market structure become more important (Orsenigo, 1989:47).

An important impact of patent protection would be on the price and market structure of agricultural and food markets. In the context of reform of agricultural supports, which will lower the price of agricultural and food products, patents could play an essential role in creating higher value market opportunities for agriculture and food related biotechnology. It may be that without patent protection, which would add significant value to crops, biotechnology innovation would be slower. Patents will not only provide protection over a company's R&D and products, but will add value to the product. Agriculture could be transformed; there is the potential of further segmenting the marketing, allowing for higher value, more specialized market niches. Patent protection then, by increasing the amount of value added which can be acquired in agricultural markets, would perhaps increase incentive for investment. Without patent protection, or some institutional shift which would reverberate on agricultural markets, making them more profitable, it is unclear whether or not this transformation would take place. If higher value markets are available, DBFs may find life easier. This depends, however, to what extent the predictions that patents will favor larger producers and increase concentration of production prove accurate. It also depends on whether or not agricultural markets have sufficient elasticity to support higher value products.

The process of promoting new institutions for new technologies, of negotiating with interest groups, of campaigning and persuading is similar to the type of activity which pharmaceutical firms had to undertake to ensure that over the counter diagnostic tests were accepted in the example given in chapter 3. While, large firms are far better equipped to undertake this activity than DBFs, the value-based opposition to patents on life, may present them with public relations problems.

6.3. CONCLUSION.

This chapter has shown that regulations and patents are highly political issues. The outcome of current debates will be decided by the way in which contending arguments are judged and the relative strength and bargaining power of participants. The debate takes place in the context of an established industry with a long history but also at a time of changing technological, institutional and social conditions. This makes outcomes hard to predict. An increasingly powerful and credible Green movement, will play a role in influencing decisions and is a social factor of which industry is becoming more aware. Pressure groups concerned with animal welfare, impact of new technologies and new institutions make life difficult for industry. The eventual regulatory regime which emerges will depend on public opinion and the level of activity of pressure groups. Stringent regulations make life difficult for DBFs and public policy aimed at supporting the DBF sector should take this into account, perhaps designing appropriate support systems. It is very difficult to establish what the effect of different regulations would be on large MNCs. Whether the extra cost would actually deter investment, will depend on how profitable the industry is and this will depend on a host of factors, including patent legislation.

Patents take a lower profile in the rhetoric surrounding biotechnology, but the implications for the way in which agricultural and food markets and therefore related biotechnology innovation evolve are no less significant. Indeed, patents may well have a more profound impact on the future shape of agricultural and food biotechnology and markets than risk regulation. This chapter ends with a brief discussion of three theoretical dimensions of the political economy and sociology of innovation of biotechnology. The connections between changes in risk regulation and patent legislation and broader systemic changes (regulation in the FRS sense) are made more explicit in this concluding section. The discussion, however, is in no way comprehensive.

First, biotechnology innovation is politically controversial. Sociologists have identified the depoliticization of technology, as it becomes increasingly identified with 'logical' economic development, as a characteristic of the 20th century. The logic of capitalism justifies innovation with reference to efficiency, competitiveness and the necessity of technical progress, obscuring the fact that innovation works to sustain a class based political economy. Habermas (1973) refers to this as 'technocratic consciousness' which pervades advanced capitalist societies. In this context, politics is delegated to experts who manage political and economic structures. The logic of system requisites becomes so pervasive that interest-based concerns, principally class politics are relatively easily dismissed. Habermas identifies the most serious threat to modern capitalism arising from a 'legitimation crisis', based on economic crisis and value conflicts (Habermas, 1973). Value conflicts do not rest on class interest, but on challenges to the culture of capitalism, which elevates the

profit motive to the guiding normative principle in capitalist societies.

There is, at least a superficial parallel between Habermas' analysis and Tait's identification of NIABY based protest potentially being the most intractable. Conflicts between different interest groups, as we have seen, are subject to negotiation; industry puts forward a very strong argument in favor of technical progress and the need for increased competition. Their victory is not automatic or complete (the farming lobby manages in some instances to win interest based arguments and industry may have to make some concessions to farmers in terms of patents and farmers rights) but, in general, the tide flows in favor of industry, which with relative ease can equate its interests with the universal economic interest with reference to competition and efficiency.

However, while industry may be able to win arguments on the basis of economic necessity, it is not considered 'legitimate'; it is not trusted in terms of its judgement about the environmental, health or moral aspects. The NIABY opposition to biotechnology comes from those who question its impact on the environment and who are skeptical about technical progress in general. Both in terms of regulation and patents, industry will have to deal with opponents who represent a different value system, one which stresses the health of the planet in general terms. While I am unable to explore this dimension of the politics of biotechnology innovation in connection with larger social trends, it is an area which warrants further research.

Second, these struggles over biotechnology relate to the political economy and sociology of agriculture. Although biotechnology has forced the issue of protection of agricultural production anew, the arguments are old. The struggle over the commodification of agriculture and

food, the implications it has for the role of public vs. private seed development and plant breeding have a long history. The renewed fervor which has arisen about patenting products of genetic engineering extends a debate about who should control plant breeding. Technical possibilities offered by new biotechnology could extend private capital's grip of agricultural output. Kloppenburg (1988) provides an analysis of the seed industry since the 15th century and analyzes previous and current battles over who should control agriculture. He makes a comparison between the type of struggle which ensued in light of new hybridization techniques in the 1920s and the 1970s. The similarity lies in private commercial breeders' efforts to "subordinate public science to its own purposes" (Kloppenburg, 1988:279). His argument is that public breeders, who have not been subject to profit criteria have shaped agriculture in important ways, keeping the price of seeds and the costs to farmers of continuously improved products low. This has played an important role in keeping the costs of agricultural production down and maintaining the objective of plentiful production, rather than the highest profit. The issue of patenting of life forms arises in the context of other efforts to privatize agriculture, represented in Britain by the selling off of public agricultural research and plant breeding stations and discussed in the previous chapter. The battle over regulations and patents must be seen in the context of this broader historical context of privatization and the extension of commodification of agriculture. In turn, the future shape of agricultural and food markets and biotechnology will be influenced by the outcome of this process. Kloppenburg, whose history is couched in the much wider context of capitalist dynamics, says,

> "Indeed, what is striking is the extent to which scientific objectives and outcomes in agricultural plant science have been and are now being shaped by forces originating in the larger political economy. Advances in genetic knowledge in the 1920s and the 1970s clearly opened new historical possibilities. Yet these advances in the forces of production did not contain specific characters that unilaterally determined the direction of technical change. Rather, existing relations of production molded the manner in which the new technologies developed...Hybrid corn galvanized extensive changes in social relations, and the new biotechnologies are now stimulating an even more comprehensive social transformation. The model of change that emerges from this analysis is fundamentally dialectical - the forces and relations of production are mutually conditioning" (Kloppenburg,1988:281).

The third set of theoretical perspectives which emerges from this discussions is related to the firm. Firms in this study have played a very active role in promoting biotechnology and lobbying for favored regulatory regimes and patent legislation. This activity has called for political decision making and action. Brunsson, (1989) contends that firms are increasingly subject to pressure to act as political actors, partly as a result of increasingly obvious blurring of the boundaries between state and industry[18]. Firms must consistently try to legitimize themselves and gain public acceptance. He says,

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[18] Many sociologists (Burawoy, (1985); Braverman, (1974); Habermas (1973) have also noted the opposite depoliticizing trend as a result of increased state intervention in the economy, although in the cases of Burawoy and Habermas the tension between politicisation and depolitization is dealt with in sophisticated ways which incorporate both aspects of the dynamic.

"Organizations in modern societies are public not only in the sense that their structures, processes and ideologies are open to observation, but also in their ultimate dependence on public acceptance, i.e. of positioning themselves in relation to the perceptions and policies of society at large. Organizations in modern societies base their legitimacy on society's perception of their contribution to the public good; they are part of the 'modern project of justice and progress'" (Brunsson,1989:216).

Managers in this study have generally shown either high levels of ignorance or disinterest in the political consequences of their actions. In the cases where managers were much more concerned with public acceptance and legitimation, (notably in MNC 4, a company which has long been at the coal face of consumer relations) these concerns have tended to be overridden by SAGB, the organization which claims to speak for large biotechnology organizations. SAGB's position is based on European industry's need to compete with the US and Japan and strenuous denials that biotechnology represents any unknown risks. Constant references to the need to compete may well backfire as it does not address the NIABY based opposition questions such as ethics, and the environmental and health impact of biotechnology. Their claims that biotechnology does not represent new hazards may not reassure an already skeptical public. The politics and sociology of biotechnology innovation, at the level of broader trends, sectoral patterns and the response of firms, may well play a key role in the future of the technology. It is an area which is ripe for further research.

CHAPTER 7. CONCLUSIONS.

Two questions guided this thesis: What are the primary influences on biotechnology innovation in the spheres of agricultural and food production? How does this relate to theoretical approaches to innovation? This final chapter addresses those questions directly.

7.1. FACTORS INFLUENCING BIOTECHNOLOGY INNOVATION.

A range of factors influencing biotechnology innovation have been identified. Factors internal to the firm and on the boundary between the firm and external environment (see chapter 2) included, organizational styles, cultural attributes, management expertise, sectoral positioning and orientation and the way in which companies pursued collaborative ventures. All these factors impacted on strategy. External factors included regulations, patent legislation, market opportunities, changes in the relationship between industry and universities, social and political pressures and, particularly in DBFs, the availability of finance and funding.

It is the interaction between different constraints and opportunities in the area of agri-food biotechnology innovation which is of importance in explaining the rate and direction of biotechnology innovation; looking at any one of these factors in isolation gives an incomplete and often inaccurate picture. For example, regulatory problems

are compounded by market constraints. Additionally, companies have not only to be concerned about the letter of regulatory law, but also about public opinion. Changes in the relationship between universities and industry seemingly contribute to an increased rate of innovation, but as chapter 5 argued, the extent to which this institutional change favored rapid technical change depended on other factors such as the nature of firms' internal organization and collaborative agreements, or the quality and quantity of funding and management expertise in DBFs. Having said this, it must be noted that the constraints on DBFs resulting from their lack of technical expertise and knowledge about development and marketing and often their separation from more downstream activities, have a more intrinsic nature. The differences between small microelectronics firms and DBFs, particularly those working in the areas of food and agriculture, are profound. The technological trajectory, a term which describes the interaction of technology and markets differs significantly in the area of microelectronics; the requisites for microelectronic production are highly skilled personnel but relatively low capital requirements. Microelectronics is a relatively clearly identifiable sector but which feeds into a wide range of other sectors. Biotechnology, on the other hand remains much more diffuse and generic. Its applications depend to a far greater extent on accumulated knowledge in sectors into which it is being fed. Thus, the outlook for DBFs is a difficult one. If a success story is defined as a DBF which manages to grow independently into a fully integrated production unit, then success stories are likely to be few and far between. As I will suggest later in this chapter, however, DBFs, can contribute usefully to biotechnology innovation.

The implications of the analysis presented in this thesis have an added dimension; constraints and opportunities exist both internally in firms and in the

external environment. Thus, successful innovation, as Amendola and Bruno (1990) suggest, results from a positive match between internal strengths and external opportunities, just as failed or problematic innovation often results from a negative match. The role of the firm in this process is not passive; firms, as we have seen in previous chapters, play an active role in trying to mold the external environment to their desired image. I will mention just two examples from the thesis to illustrate the point, although there are numerous examples from both DBFs and MNCs. MNC 1 had accumulated experience in the area of BST production. The company's previous expertise combined with new rDNA techniques and appropriate strategic collaborations allowed them to develop rBST. Despite all MNC 1's PR and lobbying efforts, however, external constraints, including negative public opinion and interest based opposition to the new technology from a politically powerful sector of the farming community, thwarted the success of the innovation. The second example is MNC 2's experience with its single cell protein product. Here the initial innovation, an animal feed substitute, again a combination of new biotechnology with accumulated internal expertise, failed as a result of changed relative prices and market conditions. The company's effort to rescue the technical achievement of the project and transform it into a higher value, lower volume meat substitute for human consumption appears to be have been more successful.

This analysis adds detail to Dosi's point, mentioned in chapter one, that innovation is an uncertain process. One important implication is that, given the fluidity of successful matches between internal and external factors, a diversity of strategies is important to national or supra-national innovation efforts. Thus, the diversity amongst firm strategy detailed in the thesis is not necessarily an indication that some firms have misjudged situations (although in some cases this may be true), but rather that

different institutions incorporate different strengths and weaknesses and will be able to relate to different facets of a changing external environment.

Two important general points arise from the analysis so far. First, the specific properties of biotechnology innovation, the context in which it arises and the sectors into which developments are channeled are vitally important. The rate and direction of biotechnology could not be understood without in-depth analysis of the technology, markets, innovating firms and context. It could not be derived from a study of general technological trends. Second, and a related point, the findings of the study are historically contingent. The study related current regulatory conditions to increasing concern over environmental and health issues and control over technology. Today's biotechnology innovation would have faced very different constraints and opportunities thirty years ago. Similarly, twenty years hence, different pressures maybe felt. It is possible, for instance, that concern over social and economic impact will increase and will take a statutory form. Similarly, biotechnology innovation has arisen in the context of institutional change in university/industry collaboration and changing agri-food markets. Markets and institutions are currently in a state of enormous flux in western capitalist countries (Aglietta, 1987; Lipietz 1987; Best, 1990; Lash and Urry, 1987; Piore and Sabel, 1984) Widespread restructuring in both public and private spheres has impacted on innovation in important ways. Added to this, third generation biotechnology is still young. Combined with social and economic instability this makes it hard to predict the nature of future trajectories in the spheres of agriculture and food. Moreover, new sectors seem likely to arise as a result of technological and market conditions, adding to the complexity.

By focusing on the particularities of biotechnology innovation and the importance of historical context in which innovation is currently taking place, I am not deriding the efforts of those who endeavor to construct broader theoretical approaches to innovation. Understanding of technical change and indeed, change in general, moves forward by the constant construction of abstract theories and subsequent critique based on carefully observed behaviour. Lipietz refers to the interaction of deductive and inductive logic, meaning the movement from study guided by abstract meta-theory to study which takes a more empiricist approach. (Lipietz, 1987) Both are necessary and both are incomplete. This thesis, does not pretend to rise to the high ground of theoretical abstraction, nor has it steadily remained on the low road in the sense that it is a purely descriptive or empirical work. It is an analytical work which posed questions and looked for answers both from interview data and from research and theoretical work done by others. The next section discusses implications of the study for theoretical perspectives of innovation. My aim is not to create any alternative meta-theory of technical change, but to provide some observations which could feed into such an endeavor.

7.2 THEORETICAL APPROACHES.

The introductory chapter laid out several reasons why the future for new biotechnology seemed bright. This study then identified reasons why innovation has proved more complex and problematic than some anticipated. These complicating facets of biotechnology innovation, in turn, shed light on broader conceptions of technical change.

7.2.1. LIMITS OF THE LINEAR MODEL AND DOSI's STYLIZED FACTS.

The linear model of innovation, outlined in chapter 1, has been shown in this thesis to be inadequate in a number of ways. Dosi's assertions that innovation is increasingly the result of learning by doing and learning by using and that cumulative activity is an important component of technical change have been borne out by a number of examples in this study. DBFs, although characteristically science intensive, were often hampered by their lack of experience in the development and production stages of innovation. They also suffered from lack of management experience and knowledge of the markets into which their innovations were feeding. DBFs, without experience of production and marketing suffered from their 'inexperience of doing'.

The concept of learning by doing implies certain things. First it suggests that the actual production process is important; learning does not happen in a linear fashion, rather technological and commercial developments often inform basic science. Second, it recognizes the importance of tacit knowledge; the people actually developing the technology will have an understanding of the technology which would not and very likely could not be written down in journals (Massey et al, 1992). The small intensive environments of DBFs should have been ideal for exploiting tacit knowledge. The environment should also have been conducive to learning associated with the development and production aspects. However, because firms in many cases did not have the resources to pursue innovation in development and marketing stages, or even identify appropriate areas, and to fully integrate R&D functions with downstream activity, this type of learning was limited.

Examples of the innovation process in large firms also point to the importance of learning by doing and using. MNC 1's development of its meat substitute is a classic example of producing a final product from previous technical experience. MNC 1's rBST was developed on the basis on previous work with BST. MNC 3 has built on experience with biopesticides to develop genetic engineering capabilities. MNC 4's whole approach is based on using biotechnology to improve processes and products in which the company has very significant technical and development skills. Their main innovative thrust is planned for areas where they are already established.

Initially one might think that the last of Dosi's five 'stylized' facts which characterizes innovation as a cumulative activity would apply less to a radical innovation such as biotechnology; that discontinuity rather than continuity would characterize radical innovation. However, in a number of respects, the point was borne out by this study. Dosi's point is expanded upon by Massey et al.

> "Technological change is not a simple response to changes in market conditions. Directions of technical change are influenced by the state of technologies already in use. The existing shape of a technology often, or even usually, determines the range of adjustments of products and process. This 'evolutionary' view of technological change has led to concepts such as technological paradigm and technological trajectory - that there are patterns along which technological change is constrained. That is, future knowledge and practice are constrained by the present...This is so at the level of whole technologies (such as microelectronics and synthetic chemistry) and also at lower levels, so that 'What the firm can hope to do technologically in the future is heavily constrained by what it has been capable of doing in the past'" (Massey et al,1992:83).

However, the importance of learning by doing and cumulative activity should not be overestimated in the case of biotechnology. As important is the process of un-learning by doing and finding ways to break with accumulated knowledge and previous technology development. In a number of cases, innovation depended on the ability of companies to 'relearn' and to break the accumulated ties. Sometimes this involved organizational restructuring, acquisitions and establishing new collaborations. MNC 2 set up an internal equivalent of a DBF, collaborating widely with outside influences, in order to do this. MNC 3, a company with considerable in-house expertise and a fully owned plant breeding company, decided eventually, to pursue a considerable element of its biotechnology activity via collaboration with a DBF. MNC 1 has established a wide array of longer term collaborations with DBFs and universities in order not to facilitate its change from one technological base to another. In a wider sense, large companies accustomed to dealing with large markets are coming to terms with the fact that higher value niche markets, seem both technologically and economically appropriate in a number of cases. This also requires an ability to adapt and change and 'relearn'. Moreover, it may be that future success depends on an on-going ability to pursue flexible and diverse strategies. The following section considers the role of DBFs in biotechnology innovation further.

7.2.2. IMPLICATIONS OF THE CRITIQUE OF LINEAR MODEL FOR DBFs.

At a conceptual level, the small biotechnology firm not only fits well in the linear model, but has a key role to play in transferring new scientific discoveries into technology. The findings suggest that DBFs have enormous problems in reaching high levels of radical innovation. Moreover, the implications of the critique of the linear

model discussed here, i.e. importance of learning by doing and cumulative activity (which contradict the linear model), also suggest that small firms, which often do not have the advantages bestowed by long established production and marketing facilities, are disadvantaged by their very nature.

However, while small firms are undoubtedly disadvantaged in some respects, these disadvantages can be ameliorated by constructive collaboration with large firms. The tension between viewing innovation as a cumulative activity and recognizing the importance of 'learning by doing' on the one hand, but on the other hand, accepting that discontinuity, flexibility and capacity to un-learn and re-learn are increasingly important principles in these times of intensive innovation puts collaborations on centre stage.

The model of collaboration, based on more horizontal links as well as vertical integration, as pursued by Japanese companies and MNC 1 towards DBFs, allows them greater possibilities. It allows them time and space in which to produce as well as develop scientific competencies. MNCs and DBFs work in parallel, each potentially benefiting from the activity of the other and building a whole body of knowledge about the development of products.

Even if, as seems to be case in Japan, according to Roberts and Mizouchi, the end result of collaboration is either sale or incorporation of the small firm, this still constitutes a very different model of innovation from the linear model. It is a model which acknowledges the importance of collaboration over a longer period of time and the importance of tacit forms of knowledge characteristic of both scientific expertise, which is often concentrated in high levels in DBFs and development activity in which MNCs have more experience. Given the

increasing pace of innovation, MNCs cannot hope to bring all useful skills in-house. In a number of ways MNCs potentially benefit from collaborations with DBFs. Specialized, highly skilled DBFs, it was argued in chapter 3 have the advantage of being able to learn rapidly. Thus, they may, given adequate resources, be able to develop technologies more radically than larger counterparts. Additionally, the fact that DBFs lie outside established sectors and do not have large stakes in existing technologies and markets perhaps puts them in a better position to move rapidly into new areas. They can act as prods to larger firms. Potentially, a model based on horizontal links can incorporate both the 'learning by doing' and cumulative aspects of technical change, together with the need to continually introduce new life and ideas and re-learn by doing.

Thus, DBFs could have a positive role to play, both in terms of innovative activity in large firms and in terms of national levels of innovation. However, their success is likely to depend to some extent on changes in large firm attitudes to collaboration. These new arrangements imply certain paradoxical forms of cooperation and competition paradoxes. The paradox could be thought of as follows: Why would large firms support smaller counterparts when by giving their support they will be forcing themselves to increase their rate of innovation and therefore expenditure? Additionally, in some cases, by supporting these companies they may also be creating direct competition for themselves. It may be that only firms which have a longer term perspective and cultures which prioritize science and technology will undertake this form of collaboration.

This paradoxical combination of cooperation and competition has been recognized by Best (1990) who considers it an increasingly important feature of new

production strategies. It is not an idea which has yet taken root on a large scale amongst industrialists and policy makers in western industrialized countries. Without industrial policy to encourage these new forms of competition, large firms are perhaps unlikely to change their mode of collaboration. Without that, DBFs, and perhaps other types of small high tech firms, are less likely to succeed and large firms may fall behind in their own capacities to innovate.

The extent to which collaborations are crucial for the health of other small high technology firms, rather than DBFs, will depend on the nature of the technology and the sectors into which small firms are feeding products. The general points made are likely to apply in most cases. Small firms have certain advantages: they are quick off the ground; their cultures are often highly conducive to R&D and innovation in science intensive areas and they are able to respond quickly to changes in the external environment. On the other hand, their size makes them vulnerable, particularly when lead times are long and R&D expensive. Moreover, their inexperience with the production process means that they cannot access an important source of innovation and lack important technical and largely tacit knowledge of the process. Their success or otherwise in taking advantage of their positive attributes and overcoming their constraints will depend, however, on a large range of specific market and technical conditions.

7.2.3. IMPLICATIONS FOR POST FORDIST THEORY.

Chapter 1 briefly outlined some of the basic premises of theories which attempt to explain the shift from Fordism to Post Fordism. The findings of this study relate in rather limited ways to these theories (this study did not examine labour process issues, for example, which are a key

component of the theories), but the relation between the study and these theories is nonetheless worth discussing.

This study found, in particular, that some characteristics of flexible specialization were absent and problematic. The prospects for small independent DBFs, as noted in chapter 3, do not, in most cases, look bright. Flexible accumulation, characterized by the emergence of new markets, new sectors and greatly intensified rates of commercial, technological and organizational innovation was certainly in evidence in this study. A crisis of mass production, in this case of commodity chemicals, propelled MNCs into biotechnology innovation. The interviews also indicated that both large and small firms were in some cases trying to identify higher value, lower volume markets in which to pursue innovation perhaps indicating a move away from standardization and mass marketing. The breakdown of institutional forms related to production and traditional markets, discussed in chapter 5, which figure as important elements in the analysis, were clear. The study found multiple expressions of restructuring which could be thought of as evidence of a shift away from Fordist production norms.

However, many managers in both large and small firms noted the limitations of niche marketing in a lower value area such as agriculture. Although the logic of biotechnology is to increase the specificity of agricultural and food products, managers were unsure if financial reward would be sufficient to make this strategy an integral part of product development. This constitutes an important critique of one variant of Post Fordist thinking which focuses on the shift to small batch production. While the theories have advanced the notion that technological forms are related to socio-economic conditions, they have tended to see the relationship in linear terms; niche technologies and new flexible forms of

industrial relations, it is implied by some authors, will lead to new socio-economic conditions in general. It may well be that increased flexibility (in the sense of increased ability to adapt to changes in the environment and more interactive patterns of organization within the firm, which allow firms to capitalize on knowledge developed in production) is proving increasingly necessary, but this does not automatically imply the widespread success of small scale production units or radical decentralization of activity in large firms. Nor does it mean an inherent tendency toward niche products and corresponding markets in every area. This the study suggests that the situation is considerably more complex; not only is innovation cumulative, limiting the extent to which 'pure' flexibility occurs, but the study suggests that market and industry structures, institutions involved in innovation, regulatory systems also have a cumulative element. Moreover, they are all inter-connected; one set of variables can provoke changes in the others. The shift to 'purer' forms of flexible specialization will be limited to sectors where a confluence of socio-economic opportunities and constraints match new forms of technology and firm level organization. This confluence will happen 'naturally' in some instances, as perhaps in the microelectronics industry in Southern California, or garment production in the Third Italy, but these limited examples of flexible specialization cannot be equated with a major shift in capitalism towards smaller scale producers in all areas.

Even if the broader category of Post Fordism is considered, rather than flexible specialization, it must be recognized that there is no linear correlation between Post Fordist practice at the firm level, flexible production and the emergence of appropriate institutions or marketing conditions. Thus, even though MNC 1 could be characterized as a Post Fordist producer, in that it makes extensive use

of networks and is moving away from reliance on the production of commodities, it is not the case, as discussed in chapter 4, that success is automatic. Moreover, the relative lack of Post Fordist characterstics in large firms perhaps suggests that a reexamination of the concept is neccesary.

Several points follow from this analysis. This thesis has argued that innovation is a social and political, as well as economic, process; this is true at the level of the firm itself and in terms of the relationship between firms and their external environment and thirdly in terms of the external environment itself in which firms have to sell products. Markets are often conceived of as neutral constructs, whereas markets studied in this thesis were clearly political and social creations. All three levels of social, political and economic activity interact and influence each other. The significance of these links is often missed by policy makers and analysts. Many DBFs, for example, fulfilled a great many requisites of Post Fordist production units. This was thought to be a good thing by national and EC based policy-makers who support small firms. However, other elements of policy either directly contribute to the failure of the same small firms (heavy regulatory costs and the lack of venture capital, for example) or are ignored as important elements of success (the importance of encouraging collaboration between large and small firms, or the basic issues of existing industry and market structures). As a consequence many DBFs have failed to achieve commercial success. The point here is that at a time of industrial restructuring, and crisis in Fordism, there is undoubtedly the potential for new forms of socio-economic and technological structures. But the process of change is exceedingly complex. The type of Post Fordist future based on horizontally linked small production units cannot be created by entrepreneurs and new technology alone, it would require a political commitment

to strategic change in a wider system. As the system exists, DBFs cannot compete with larger counterparts. It may be that the existing system is not the most efficient economically or desirable politically, but it is not clear whether small production units would prove more efficient in all sectors. Whether or not small or large units would prove more efficient depends on the existence or absence of economies of scale, potential for market segmentation and diversification and the type of knowledge and capacity needed to pursue these opportunities. For example, we saw in the case of biotechnology and plant breeding, that while there was potential for niche marketing the economics of product development in this area remained unclear. Moreover, even though genetic engineering was key to new opportunities, new technology could only be used successfully in conjunction with traditional techniques and knowledge.

The second point, then, which is worth raising on the basis of findings of this study, is whether the equation of small "craft producers" in the terminology of Piore and Sabel and future competitiveness is an accurate one. In the debates about Fordism, Post Fordism and flexible specialization there has been a confusion between analysis which tries to more clearly identify the links between different aspects of economy and society, discuss the politics of technology and identify the potential of increased flexibility to resolve a crisis in Fordism and an approach which more resembles Schumacher's 'Small is Beautiful' approach (Schumacher, 1973). In the flexible specialization approach, flexible is small scale and is equated with successful innovation. One of the important constituents in Piore and Sabel's analysis is the identification of 'craft knowledge', whereby producers compete on the basis of traditional skills and specialize in areas where they compete on the basis of intimate knowledge of relevant processes; they learn by doing and

gain invaluable tacit knowledge. However, Piore and Sabel do not deal with the fact that in order to build up tacit knowledge, some form of stability is required and large firms are in many respects better equipped to learn by doing. There is a contradiction in the idea that small firms can compete on the basis of tacit knowledge, when the environment requires that they are in a constant state of flux. Being in a state of constant change and pursuing survival tactics is not the same as being flexible. What is actually likely to happen in these situations is that small firms become inflexible; they do not have the time or resources to pursue a wide range of production possibilities. In this study it was seen that instability in the markets, regulations, patent legislation and public policy created a difficult atmosphere in which to innovate. In a way a high level of instability of the environment limited the amount of flexibility which could take place in firms. This was especially true of smaller firms which often had to limit their flexibility both in terms of R&D priorities and production and which were, in the context of instability, in many cases ill-equipped to cope with high R&D expense and long lead times. Thus, although they could respond quickly to new advances in science, they were in many cases not able to translate research into a wide range of developed products. The situation of DBFs, as noted in chapter 3, did not fit happily with the role assigned to them by flexible specialization theorists such as Piore and Sabel. Large firms, on the other hand, although slower off the ground, where able to be more flexible in the sense that they could apply accumulated knowledge over a wide range of production processes and products.

While DBFs did have important forms of tacit or craft knowledge relating to R&D, Teece's (1986) analysis that the owner of 'complementary assets', such as development and marketing skills will tend to benefit from innovation, rather than those at the science end of the process seemed

to apply in this case. The most likely candidates for flexible production are perhaps those large firms which manage to use their facilities to learn by doing and communicate the learning. Small firms engaged in longer term collaborations with larger firms do have a potentially beneficial role to play as explorers and promoters of new techniques to large firms and could have a much greater contribution to make in this respect if large firms were to change their behaviour patterns. However, the capacity of large firms to build up knowledge over a wide range of areas, to learn by doing and build cumulatively broad areas of expertise, makes it likely that they will be more efficient innovators in many areas. The conclusions of this study suggest that while types of collaborative agreements may benefit both large and small firms, large firms have some significant advantages over smaller counterparts in the areas studied.

The findings of the study seem congruent with a number of components of the analysis which focuses on the breakdown of Fordism, but point to gaps in the more predictive analysis, such as that of Piore and Sabel, which focuses on new opportunities for small firms and flexible specialization. The problems of DBFs, it has been suggested are both contextual (lack of finance, and specificities of agricultural and food related biotechnology innovation for example, reluctance of large firms to engage in longer term collaborative efforts) and more innate in that they are separated from other parts of the production process. Some Post-Fordist theorists, particularly those who are very enthusiastic about flexible specialization have not acknowledged the problematic aspects of small firm innovation which this study of DBFs has shown and which the critique of the linear model of innovation established. Neither does the theory provide adequate conceptualization of sectoral and market specificities.

Areas which are in need of further research include: the nature and value of collaborative ventures; the role of small firms in innovation and in industrialized economies; and the nature of flexibility in production and industry needs both empirical investigation and conceptual clarification.

Another theme which has run through the thesis is the social and political nature of innovation. The following section discusses these points.

7.3 THE POLITICS OF INNOVATION.

Issues to do with firm organization and collaboration are undoubtedly political in the sense that they are intimately connected with public policy and social context This thesis also pointed out another set of political and social issues which impact on innovation. The influence of regulations and patent legislation on biotechnology and the response of firms have been detailed in previous chapters. The impact of these factors on innovation was discussed in chapters 3 and 4. Chapter 6 expanded upon this discussion and also examined firms' responses to what are essentially issues of politics, political economy and social movements. A number of issues are salient in terms of theoretical approaches. The first is that theories of innovation which limit themselves to examining the interaction between economics and technology miss important sociological and political dynamics. There has been significant work done in the area of the social shaping of technology, but much of the writing has glossed over the central importance of the firm (Green, 1991). The firm as the channel for innovation is also the vessel which has to be guided through the social and political waters. This thesis has focused on how managers in firms perceive that emerging regulations and patents will impact on innovation and how

they act to shape the environment to their best advantage. Chapter 6 suggested that it is not sufficient that firms, in order to be competitive, be efficient and productive, but that they also be must legitimate.

In using the term politics of innovation, I am suggesting that attention needs to be paid to the issues discussed in chapter 5; to the dynamics between broader institutional factors, (the balance between private and public institutions, for example) economic factors and related policy which affects market conditions and technological innovation. But, I am also thinking of the need to pay more attention to two additional areas. First, Chapter 6 focused on the perceived impact of regulations, patents and influential social movements and environmentalist organizations. It was suggested that it is no longer sufficient for firms to produce efficiently, but that they must legitimate themselves in normative terms. The extent to which firms will have to confront this kind of pressure, of course, depends on the type of innovation, with some technologies being much more controversial than others. It will also depend on the level and nature of social and political concern at any time, legitimation being much harder to establish at some points than others. The access which each group has to political power structures also has to be considered. In this respect, it is interesting to note the centrality of EC structures and institutions in the battle over biotechnology regulations and patents. The new structures which have come into operation for evaluating risk and establishing institutional ground rules for technology have certainly changed the operating environments both for firms and for pressure groups. Beyond very general statements such as these it is difficult without more research to identify possible changes in the balance of power.

The second point relates to the consideration of firms operating in biotechnology innovation as political actors, particularly the large firms which have much more political influence. The political activity of firms, as the thesis has suggested, goes beyond public relations exercises, with extensive lobbying of policy makers. The interaction is obviously key to market creation. Yet, policy makers have different concerns and are engaged in internal political disputes. This aspect of the social and political construction of markets is an area which would be extremely interesting to investigate further. In terms of biotechnology further analysis of the type of opposition to biotechnology and a more detailed examination of firm strategy and the motivation behind it would be a useful contribution to further understanding the politics of innovation in this area. This type of study would have to attempt to assess the real impact of horizontal vs. vertical regulatory regimes. More theoretical work would include conceptualization of political power in relation to market structure, political structures, type of technology and product, amount of state ownership or regulation and business cultures.

7.4. CONCLUSION.

This thesis identified factors influencing biotechnology innovation in large and small firms. The analysis focused on decision making in firms. The thesis also considered wider dynamics implicated in the innovation process. In large firms, external factors shaping decisions about the technology included economic and political perceptions, regulatory issues concerning both risk regulation and patenting. Factors internal to these firms which influenced key relevant decisions were company culture, organization, and previous areas of corporate activity. Factors influencing decision making and

innovation in small firms were in some cases similar to those in larger counterparts but DBFs were heavily constrained by lack of funding, difficulties associated with venture capital and lack of appropriate knowledge relating to technical and non-technical aspects of innovation. The findings of the study highlight a series of erroneous assumptions built into the linear model of innovation. Together with problems identified in DBFs, cumulative aspects of innovation and the importance of 'learning by doing' constitute elements of the critique of the linear model. For overlapping reasons, aspects of Post Fordist theories, particularly those emphasizing flexible specialization as a new model of industrial organization in advanced industrialized countries were also seen to be problematic.

The thesis examined social-economic and political aspects of innovation of biotechnology, both within the firm and in the wider business environment. Institutional and market structures of significance to the future direction of the technology were examined in some detail, as were debates and controversy over risk regulation and patents.

Many studies of innovation look at the process either from the point of view of how forces external to the firm shape technology or how the firms itself innovates. This study holds that innovation can better be understood if both these perspectives are adopted; the firm is the primary institution in which innovation occurs in industrially advanced countries, but it cannot be considered in isolation or in narrow economistic terms. Recent theoretical and methodological works have begun to adopt this approach which views innovation as a process of change in both the firm and external environment. The description and analysis presented here hopefully

contribute to an ongoing effort to better understand the nature of technical change.

APPENDIX.

GLOSSARY OF TERMS.

Amino Acid. Basic building block of proteins.

Antibody. Protein produced in response to exposure to a specific antigen and characterized by its specific binding to the complementary antigen. Important in defense against disease-causing organisms.

Asexual. Describes the reproduction of a living organism without sex; characteristic of microbes, and also alternative form of reproduction in many plants.

Bacterium. Small single-celled organism.

Biocatalyst. Biological catalyst; can be either an enzyme or a cell with the required enzyme activity.

Biochemistry. The study of the chemistry of living things.

Biofuel. Biologically produced fuel, e.g. biogas, ethanol.

Biomass. Total of organic material in living and dead plants and animals.

Biosynthesis. The production of complex chemicals from simple precursors, carried out by all living organisms.

Catalyst. A substance which speeds up a chemical reaction without itself undergoing any net change during the reaction.

Cell. The basic unit of which living organisms are made; some organisms are just a single cell (e.g. bacteria, some algae and protozoa while many are multicellular.

Cell culture (tissue culture) The in vitro growth of cells isolated from multicellular organisms.

Chimera. An animal whose cells are derived from two or more different individuals, even ones of different species.

Culture. Collective term for cells and the medium in which they are grown.

DNA (deoxyribonucleic acid) The genetic material. The genetic message coded in the sequence of DNA bases is transcribed into mRNA and this message then translated into protein.

Embryo. Early stage in the development of an animal or plant.

Enzyme. A biological catalyst. All enzymes are proteins.

Eukaryote. An organism composed of cell(s) with membrane-bound structurally discrete nuclei. Eukaryotes include all organisms except viruses, bacteria and blue-green algae - these are called prokaryotes.

Feedstock. Starting material used in industrial/biotechnological or food processing.

Fermentation. Any process in which microbes metabolize an organic substrate.

Gene. The basic unit of hereditary: a sequence of nucleotides comprising a segment of DNA (the information is in the sequence of bases; a basic is part of a nucleotide.

Gene Expression. The whole process by which the message (information) contained in a gene directs the synthesis of a specific protein.

Gene Probe. A short piece of DNA that can recognize and bind to complementary DNA in a specific gene, thus indicating the presence of that gene.

Gene therapy The treatment of an inherited disease by inserting normal versions of the faulty genes into the patient's cells.

Genetic diversity. Heritable variation within a species.

Genetic engineering. General term used to describe any artificial procedure whereby genes are transferred from one organism to another.

Herbicide. Weedkiller.

High Fructose Syrup. Sugar syrup produced commercially from maize (corn) starch comprising glucose and fructose.

Hormone. Chemical messenger in the body; carried in the bloodstream from the hormone-producing gland to the target cells which respond to the 'message'.

Hybridization. The binding (annealing) which occurs between two complementary strands of DNA (or DNA-mRNA).

Hybridoma. A cell which is produced by the fusion of a myeloma cell (cancer cell which divides continuously in culture and is 'immortal') can an antibody-producing cell; the resulting cell grows in culture and produces monoclonal antibodies.

Immobilization of enzymes or cells. Confinement by attachment to or entrapment within an inert material.

In vitro. Literally, 'in glass'; relating to biological processes taking place outside the whole multicellular organism.

In vivo. Literally, 'in life'; relating to biological processes taking place within a living cell or organism.

Inorganic Compound (inorganic chemical). Substance not containing the element carbon.

Insecticide. A substance that kills insects.

Methane. A gaseous hydrocarbon used as a fuel, more usually known as natural gas. The main component of biogas.

Microbe (micro-organism). A microscopic organism (generally single-celled); e.g. bacteria, protozoa and many fungi are microbes.

Monoclonal Antibodies. Homogeneous antibodies produced by a single clone of cells. Monoclonal antibodies are used medically in diagnostics and industrially for high-resolution chromatography).

Mutation. Any change in the genetic material; mutation can be at the level of the whole chromosome as in Down's syndrome or just a change in one or a few bases within a gene.

Nucleic acid. Biological polymer (e.g. RNA, DNA) composed of chains of nucleotides.

Nucleus. The structure within a eukaryotic cell which contains the chromosomes.

Organic compound (organic chemical). Substance containing the element carbon.

Pesticide. Chemical used to protect crop plants.

Protoplast. A plant or microbial (e.g. yeast, bacterial) cell from which the rigid cell wall has been removed.

Protoplast fusion. The process by which two protoplasts are brought into close contact so that their cell membranes become continuous and their cytoplasms can mix freely, thus forming a single hybrid protoplast (cell).

Recombinant DNA (rDNA) The hybrid DNA produced by joining pieces of DNA from different organisms together in vitro.

Selective breeding. Procedure of carrying out crosses (matings) between desirable individuals to produce next generation of plants or animals.

Single Cell Protein (SCP) Cells, or protein extracts, or microbes grown in large quantities for use as human or animal protein food.

Somaclonal variation. The variation observed between plants grown from cells or protoplasts isolated from an identical genetic source.

Splicing DNA. The joining of one DNA molecule recombinant DNA.

Virus. The smallest and simplest form of living material. A virus consists often of a small piece of genetic material surrounded by a protein coat. It is dependent upon a host cell (microbial, animal or plant) for multiplication.

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