INNOVATION IN AGRO-FOOD BIOTECHNOLOGY: A STUDY IN TECHNO-SCIENCE

Kemal Ahson

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

January 1999

University College London

ABSTRACT

Biotechnology is of strategic importance to modern capitalist societies, but is currently in a controversial and transitory phase of development. This thesis examines contemporary innovation in agro-food biotechnology. It identifies the products and processes associated with agro-food biotechnology, and the means by which they come about. In particular, it investigates the connections and interactions between various cultural, economic, political, scientific, social and technological elements in biotechnological innovation, some of the features of where and how innovation takes place, and the key actors and institutions that influence these arrangements and interactions. It treats innovation in agro-food biotechnology as a phenomenon embedded in broader human-technology relations, and develops a multi-dimensional approach to the understanding of biotechnological innovation.

Using the spatial form of the network, biotechnological innovation is conceptualised as a multiplicity of networks which link various actors, activities and conditions together. Surveying and in-depth interview research techniques are employed to identify and examine these networks. The empirical work traces particular networks of biotechnological innovation from points in Denmark and the Netherlands, across Europe, to the UK.

Five key findings are reached. First, there is an enormous discrepancy between current and potential developments in agro-food biotechnology as only a limited range of food processing aids and raw materials are being commercialised. Second, there is considerable uncertainty with the term 'biotechnology' which has practical implications for the developmental trajectories of biotechnology. Third, biotechnological innovation entails a diverse and ambiguous set of actors, activities and conditions whose ends are not readily predictable. Fourth, there is a dialectical relationship between agro-food biotechnology and the means by which it comes about, as biotechnological innovation shapes, and is shaped by, biotechnology. Fifth, biotechnological innovation not only involves connections and interactions between social and technological factors, but also entails cultural and existential exchanges.

ACKNOWLEDGEMENTS

I would like to thank Richard Munton, my supervisor, and Peter Wood and Phil Crang, my supervisory committee, for all the guidance, encouragement and advice they have given me during the completion of my PhD.

I would also like to thank other members of staff in the Department of Geography, University College London, especially Matt Gandy and Hugh Prince, for their constructive comments.

A number of my fellow PhD 'candidates' - Andrew, Ben, Iain, Jeremy, Kuheli, Long, Nicole, Ulf - made the different stages of the PhD more bearable. Many thanks to them.

I am indebted to a number of friends - Heather, Jimmy, Julie, Lisa, Miranda, Nick, Piers, Rama, Rannveig, Sadie, Sunita, Vanda - who (in)directly shared my experience of doing a PhD.

I am grateful to the individuals and organisations which participated in the study. Without their co-operation this thesis would not have been possible. Unfortunately in most cases I cannot disclose their personal or organisational names, but their assistance and input are greatly appreciated.

I am also grateful to the Economic and Social Research Council, and the Graduate School and Department of Geography, University College London, for funding this research.

Finally, I thank my family - Mum, Shaista, Yasmin, Sara, Samir, Sofia, Marium and Khalood - for just being there over the years. I end these acknowledgements by dedicating this work to my late Father who would have enjoyed this 'intellectual excursion'.

CONTENTS

ILLUSTRATIONS

Figures

Tables

LIST OF ABBREVIATIONS

ACNFP	Advisory Committee on Novel Foods and Processes (UK)
ANT	Actor-network theory
BMB	Biotechnology Means Business (UK)
CAP	Common Agricultural Policy
CEC	Commission of the European Communities
DBF	dedicated biotechnology firm
Dfl	Dutch Guilders
DG	Directorate General (CEC)
DKK	Danish Krona
DNA	deoxyribonucleic acid
DRHP	diet related health problems
DTI	Department of Trade and Industry (UK)
ECU	European Currency Unit
EFB	European Federation of Biotechnology
EP	European Parliament
EPA	Environment Protection Agency (Denmark)
EPO	European Patent Office
EU	European Union (formerly known as the European Community [EC])
FAC	Food Advisory Committee (UK)
FAO	Food and Agricultural Organization
FDA	Food and Drug Administration (US)
FDF	Food and Drink Federation (UK)
GM	genetically modified
GME	genetically modified enzyme
GMO	genetically modified organism
HGP	Human Genome Project
IPR	intellectual property rights
MAFF	Ministry of Agriculture, Fisheries and Food (UK)
MANMF	Ministry of Agriculture, Nature Management and Fisheries (Netherlands)
MEA	Ministry of Economic Affairs (Netherlands)
MECS	Ministry of Education, Culture and Science (Netherlands)
NFS	National Food Survey (UK)
OECD	Organization for Economic Co-operation and Development
PCR	polymerase chain reaction
PWT	Stichting voor Publieksvoolichting over Wetenschap en Techniek (Public, Science and Technology Foundation) (Netherlands)
R&D	research and development
rDNA	recombinant DNA
RNA	ribonucleic acid
SAA	strategic alliance activity
TNO	Netherlands Organisation for Applied Scientific Research
UCL	University College London
UNEP	United Nations Environment Programme
UNESCO	United Nations Education, Science and Culture Organization
WIPO	World Intellectual Property Organization
WTO	World Trade Organization

1

INTRODUCTION

1.1 Overview

Biotechnology is of strategic importance to modern capitalist societies, but is currently in a controversial and transitory phase of development. This thesis examines contemporary innovation in agro-food biotechnology. It identifies the products and processes associated with agro-food biotechnology, and the means by which they come about. In particular, it investigates the connections and interactions between various cultural, economic, political, scientific, social and technological elements in biotechnological innovation, some of the features of where and how innovation takes place, and the key actors and institutions that influence these arrangements and interactions. It treats innovation in agro-food biotechnology as a phenomenon embedded in broader human-technology relations, and develops a multi-dimensional approach to the understanding of biotechnological innovation. In sum, this thesis is a study in techno-science.[1]

There is a growing consensus on the importance of modern biotechnology (hereafter biotechnology) for modern capitalist societies (OECD, 1989; Bud, 1993; Fransman et al., 1995; Grace, 1997; King, 1997; Hamilton, 1998). The Commission of the European Communities (CEC) (1993, 1998a:7), for example, considers it to be 'one of the most promising and crucial technologies for sustainable developments in the next century'. On a superficial level, recent figures suggest that the value of products and services using biotechnology in Europe is estimated to be around ECU 40 billion per annum with about 300-400 000 associated jobs (Europabio, 1997:10); for the year 2005, the projected figures for value and employment are ECU 250 billion and 3,100-3,300 000 respectively (ibid.:77). Defined in terms of 'the application of biological organisms, systems, and processes based on scientific principles, to the production of goods and services' (OECD, 1992:29), biotechnology

[1] Hereafter, I use the unhypenated 'technoscience'. But as will be explained in **Chapter 7**, for the purposes of analysis I use the hyphenated 'techno-science' later on in this thesis.

penetrates many aspects of our lives.[2] For instance, it is increasingly claimed that biotechnology will bring about fundamental changes in the food and drinks that we consume and the means by which they are produced (EFB, 1994; MAFF, 1994; *Guardian*, 1997a, 1997b; *Science Museum*, 1997; FDF, 1998; Wymer, 1998). More generally, biotechnology is being developed and used in a range of industrial sectors covering pharmaceuticals (drugs and human health care), agriculture and forestry, foods and feeds, chemicals, and the environment (OECD, 1989; Price, 1995; Grace, 1997; Hamilton, 1998).

But the importance of biotechnology is not purely economic or productive. There are other important dimensions to biotechnology. First, it raises important questions about the nature and type of relationships between, for instance, public and private interests involved in economic activity. One aspect of this relationship centres on the contemporary policy debate about the regulation of biotechnology. Whilst strong arguments against regulation persist amongst industrial concerns (Greenberg, 1995; Shohet, 1996), public institutions are widely engaged in regulating both the development and use of biotechnology (Miller and Flamm, 1993). But there are many challenges to the role of public regulation (Maryanski, 1990; Vaucheret and Tepfer, 1993; Humphrey, 1996); for example, responsibility towards consumers to ensure that biotechnology is safe to develop and apply (ACNFP, 1990) must be balanced against the need to ensure that regulation does not have a negative effect on the competitiveness of industrial interests in the biotechnology sector (CEC, 1994). Unsurprisingly, the regulation policy debate area has been marked by a confrontational exchange involving a wide range of actors and interests representing both national and international interests (Tait, 1990; Levidow et al., 1997). How these actors and interests interact with each other, such as in the development and adaptation of intellectual property rights (IPR) (Lehmann, 1998; van Wijk, 1998), or in the mix of public and private funding (Ernst & Young, 1996) and multinational and venture capital (Kenney, 1995; CEC, 1998b), is leading to complex sets of institutional and structural arrangements between public and private interests (Goodman and Watts, 1994; Blumenthal et al., 1996; Haber, 1996; Buttel, 1998).

[2] I use 'biotechnology' in the singular for the purposes of simplicity and style, but it is worth pointing out that both 'biotechnology' and 'biotechnologies' are used equally throughout the literature.

Second, biotechnology is also at the centre of a debate about the changing nature of science and technology. Biotechnology comprises an assortment of techniques and technologies with potential applications in many economic sectors (NEDC, 1991; OECD, 1992; Europabio, 1997). For some authors, this development is seen to be part of a 'tripod' of new technologies consisting of biotechnology, micro-electronics and new materials (Roobeek, 1995), leading to a 'new' techno-economic paradigm which opens up new economic possibilities (Freeman, 1991; Fransman et al., 1995; Castells, 1996). Fundamentally, biotechnology plays an important role in facilitating greater interaction between areas of knowledge and disciplines (Elliot, 1988) and encourages a blurring of the pure and applied distinction in science and technology (Betz, 1998). Moreover, biotechnology is at the centre of developments in the emergence of technoscience[3] (Tiles and Oberdiek, 1995; Rabinow, 1997:10). But equally, biotechnology is at the heart of a general ascendancy of the life sciences within the academy and society generally (Bronowski, 1977; Sinsheimer, 1983). For example, as well as the enormous amount of funds biotechnology is attracting, such as in the Human Genome Project (HGP) (Balmer, 1996),[4] such technology is often accompanied by a sense of moral authority (Kaye, 1986), as seen in its proposed remedies for the limitations of chemical-intensive agriculture (Levidow, 1996:55). Biotechnology, then, is intrinsically multi-/inter-disciplinary, necessitating new economic and moral spaces with more flexible boundaries, and re-defining the interface between science and technology.

Third, biotechnology is at the heart of a number of key epistemological-cum-ontological concerns for modern capitalist societies. Although science and technology are often treated as a privileged body of knowledge (Elliot, 1988:1), this position is increasingly being questioned (Soper, 1996; Wynne, 1996), leading to changes to their authority (Yearley, 1997). Biotechnology, through the field testing of genetically modified (GM) crops or the foods derived from such crops, may pose risks to ecosystems or human health (Grace, 1997; *The Splice of Life*, 1997a; *Economist*, 1998). These risks are posing unique dilemmas, not only in terms of how they are to be managed (Goldberg and Greenlee, 1993), but also where

[3] The emergence of 'technoscience' is discussed in **Section 2.3**.

[4] In the UK, the Government has recently announced an extra £1 billion for the research councils and higher education funding councils, singling out the 'life sciences' as a priority area (*Research Fortnight*, 1998).

responsibilities for these risks lie (Benton and Redclift, 1994). In the so-called 'risk society', where technology is said to be increasingly removed from the political arena (Beck, 1992, Beck et al., 1994), individuals are finding it difficult to deal with risks associated with biotechnology in everyday life (Levidow, 1996). Furthermore, biotechnology is questioning the society-technology (Menser and Aronowitz, 1996; Haraway, 1997; Kerr et al., 1998) and nature-technology dichotomies (Berland and Kember, 1996; Robertson et al., 1996; Buttel, 1998; Squier, 1998). For example, through the nature of transgenic animals and crops (Haraway, 1992), the possibility of genetic improvements of reproductive lineage (Beck-Gersheim, 1996), and even the ability to change our bodies (Terranova, 1996), biotechnology may facilitate new ontological shifts for human societies. In this respect, biotechnology can be thought to have existential overtones as human-(bio)technology relations play a deeper role in the formation and development of human society (Ihde, 1979). As well as a function of social and economic interests (Law, 1988), (bio)technology reflects wider concerns about the essence of modern capitalist societies (Heidegger, 1966, 1977).

Undoubtedly, biotechnology has important and radical implications for modern capitalist societies. But what can be said about biotechnological innovation? Generally, the study of biotechnology by social scientists has been examined within a narrow perspective which displays (at least) three features. First, mirroring a more general trend in the study of science and technology in social science (MacKenzie and Wajcman, 1996:2), much research has concentrated on the socio-economic and political antecedents to, and/or consequences of, biotechnology.[5] Some recent examples of completed work that reflect this focus cover the structural organisation of economic activities (generally, Hacking, 1986; OECD, 1989; NEDC, 1991; Marks, 1993; on agro-food systems, Goodman et al., 1987; Marshall et al.

[5] Academic interest in biotechnology has been huge; consequently the literature is almost impossible to outline at modest length. The interest in biotechnology has not only been academic. There is growing interest, concern and controversy on issues related to the role of biotechnology in society generally. Newspapers, journals and television programmes are replete with references to it. In the provision of food, for instance, whilst there is some consensus on the potential benefits biotechnology could bring (Marshall et al., 1996), there remains considerable consumer resistance to the manipulation of food by biotechnology (Zechendorf, 1994; FDF, 1996a). By the same token, as reflected in the recent proposal for human cloning as part of an infertility treatment (*Guardian*, 1998a; *Independent*, 1998a), despite some acceptance of biotechnology by consumers in the provision of human and animal health care (Marlier, 1992), this recent proposal ensures that biotechnology remains a controversial issue. On a rather different note, biotechnology has figured in a number of 'horror' films such as Boys from Brazil, dna, Jurassic Park and Alien Resurrection.

1996; on the pharmaceutical sector, Kwaak van der and Hersbach, 1993; *Economist*, 1995, Hodgson, 1997a; on changes in employment, Ahmed, 1995; and international competitiveness, Ernst & Young, 1996, 1998; Europabio, 1997). Similarly, considerable research has been conducted into the impact of biotechnology on international trade patterns (Junne, 1990, 1995), trade conflicts (Peterson, 1989; Byman, 1990) with respect to developing countries (Ahmed et al., 1992; Dasilva et al., 1992), and the socio-political effects of biotechnology in both industrialised countries (King, 1997) and developing countries (Meagher, 1990; Otero et al., 1997). More recently, work has been carried out on the development of regulatory and legal mechanisms at both a national and international level (Goss, 1996; Humphrey, 1996; Shohet, 1996; Wiktorowicz and Deber, 1997; Levidow et al., 1997), and public perceptions of biotechnology (Baker, 1995; Macintyre, 1995; Eden, 1996; Hagedorn and AllenderHagedorn, 1997; Michael et al., 1997; Schibeci et al., 1997). For all this, much less work has been carried out on biotechnological innovation.

Second, the research outlined above has generally been marked by a tendency to separate biotechnology from the means by which it comes about. There is a general recognition that (biotechnological) innovation can refer both to a process and a product (OECD, 1981; Tornatzky and Fleisher, 1991; CEC, 1996a), and some academics believe that maintaining some form of distinction between the two is necessary when organising studies of innovation (Hippel von, 1988; Utterback and Abernathy, 1993; Ford, 1995; Slappendel, 1996). But this view encourages a 'materialist' notion of innovation (Barley, 1990) in which technological innovation is assessed in terms of its 'outputs'. What is virtually absent from such accounts is a clear appreciation that biotechnology, as products and processes, is inextricably linked to the means by which it emerges (see, for example, Howells, 1994). That is, early attempts to explicate the full sweep of products and processes - and the affect they have - have been separated from, for instance, the social and economic factors and institutions which influence their emergence. In a general sense, then, biotechnology and biotechnological innovation have been treated as two distinct and separate areas of enquiry.

Third, and more specifically, research on biotechnological innovation has concentrated on a rather narrow set of issues. One issue, for instance, is the

importance of the nature and type of corporate relations, such as strategic alliances, that characterise innovation in biotechnology (Hagedoorn, 1993; Kotabe and Scott Swan 1995; Prevezer and Toker, 1996), especially in relation to the strengthening of links between universities and dedicated biotechnology firms (DBFs) (Kloppenberg, 1988; Kenny, 1995). More generally, there has been work on the effects of clustering and geographies of proximity associated with (bio)technological innovation (Massey and Wield, 1992; Massey et al., 1992; Shotet, 1994; Haug, 1995; Swann and Prevezer, 1996), and the management of change in biotechnological innovation, especially with regards to 'successful' innovations (Omta, 1996; Betz, 1998). Finally, through laboratory or specific case examples, there have been attempts at exploring and understanding the range and complexity of factors that make up innovation in biotechnology although these have generally been confined to the activities of firms (McKelvey, 1996; Rabinow, 1997). Little research has identified and examined the complexity of the wider 'innovation milieu' and how this shapes, and is shaped by, biotechnological innovation.

Despite - or perhaps because of - the gaps in our understanding, which arise in part from the early developmental stage of biotechnology, there is clearly a need to undertake further theoretical and empirical work on innovation in biotechnology. In particular, what are the actual developments in biotechnology and how do they differ from potential developments? What are the key actors and institutions shaping biotechnological innovation, and how do they interact with each other? How are the various cultural, economic, political, scientific, social and technological aspects of biotechnology connected to each other in innovation?[6] How do various disciplines and areas of knowledge in science and technology combine and connect in biotechnology to form multi-/inter-disciplinary approaches? What are the links between the effects and causes of biotechnological innovation? And does biotechnological innovation play a role in forming broader human-technology relationships? This study addresses these concerns.

[6] To avoid the repetitive writing of 'cultural, economic, political, scientific, social and technological', I will use 'social' and 'technological' in this thesis.

The foundation upon which this thesis is based is four-tiered.[7] The first centres on the idea that modern society is essentially capitalistic. Modernity, as Miller (1994:291) writes, is 'more often evoked that described'.[8] Academic interest in modernity is huge although there is a core tradition of works (for which, see Miller, 1994:10-11). Many writers highlight the considerable controversy over how to explain or categorise modern social life (Frisby, 1986:1; Latour, 1993:10-11; Redclift and Benton, 1994:11; Kumar, 1995:194; Turner, 1995:1).[9] But following Giddens (1990:11), it can be argued that 'the emergent social order of modernity is capitalistic in both its economic systems and other institutions'. Whilst it is increasingly recognised that capitalism cannot be totally equated with modernity, it is reasonable to assert that it is an integral part of the modern project (Albrow, 1996:30). Therefore, for this thesis, modernity is understood as integrally linked to the rise of capitalism and its consequences (Halton, 1995:264; Kumar, 1995:31). Importantly, whilst capitalism is based on the accumulation of capital (Wallerstein, 1990:36), there is a growing sense that it is going through fundamental changes (Harvey, 1989; Amin, 1994; Schoenberger, 1997). One such change is the need to accelerate the processes of capital accumulation and circulation (Harvey, 1996:411). This apparent tendency of capitalism towards over-accumulation (Harvey, 1989; Friedland and Boden, 1994:30) represents a complex rhythmic cycle of economic expansion and contraction (Schumpeter, 1939; see also **Section 2.4.1**). Thus, as Marx

---

[7] Despite the simple sketch of these 'tiers', they help lend insight into how biotechnological innovation is investigated in this study.

[8] Casting this research purely in terms of 'modernity' is not the aim of this thesis. Quite apart from the many gaps - theoretical and empirical - in the account of innovation in agro-food biotechnology, there is a general sense that any broad claims or narrative about modernity cannot (and perhaps should not) be made from the arguments and examples presented in this thesis. Therefore, no broad survey and summary of the literature of modernity (for which, see Turner, 1996) is required here.

[9] Commentators on modernity can be roughly divided into those who believe that current social life can (still) be considered modern (Berman, 1983; Habermas, 1985; Giddens, 1990; Miller, 1994) and those who reject this notion (Vattimo, 1988; Bauman, 1991; Waugh, 1992; Lyotard, 1993; Touraine, 1995). Despite the controversy associated with identifying and explaining modernity, it seems difficult to ignore it (cf. Latour, 1993; Thrift, 1996). Given the disagreements over the form and dating of modernity (Bauman, 1991:3) it is possible to argue that 'modernity' as a term is redundant and does not explain our current conditions. In fact, as noted by some commentators, interest in modernity has been replaced by concern over globalisation (Albrow, 1996; Cook and Crang, 1996; cf. Leyshon, 1997). Nevertheless, for this thesis, following Miller (1994:2), who believes arguments about modernity are both empirically plausible and theoretically sustained, when thinking about changes in modern capitalist societies I find it a useful concept.

argues (1973 in Elliot, 1980:26), capitalism is a form of economic and social change that displaces old equilibria and creates radically new conditions.[10]

Second, innovation, and technological innovation specifically, are the key dynamic for change and development in capitalism. For Schumpeter (1939:86) innovation is the 'outstanding element in the history of capitalism', and he places it at the centre of theories of economic growth (Freeman, 1991:76; Hagedoorn, 1994). Innovation has many dimensions: it can refer to both a 'process' and a 'result'; it can be 'incremental' or 'radical' depending on whether it leads to modifications of existing products or processes or to novel ones which alter the market substantially (OECD, 1981; Freeman and Perez, 1988; Afuah, 1998). But unlike the suggestion in much of the literature, the importance of innovation is not restricted to the market strategies of commercial firms; instead it needs to be understood as part of a broader dynamic process of change and replacement - 'creative destruction' - that is the source of both instability and growth in capitalist societies (K. Smith, 1996:108). In a similar vein to Marx,[11] Schumpeter (1976:83; italics in the original quote) writes on innovation, 'it revolutionizes the economic structure from *within*, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism.' Innovation, therefore, maintains capitalism by generating and transforming capital.[12]

Third, the emergence and development of technoscience is one of the most important aspects of innovation in capitalism. As Bhaskar (1993:333) notes, science and technology, and the interactions between them, reflect the 'essence of the logic of capitalism'. Although in recent years there has been some debate over the primacy of science and technology in society (Lyotard, 1993), technoscience is seen

---

[10] According to Harvey (1989:107), both Marx and Schumpeter's analysis of capitalism is not purely economic but is seen in the wider context of social history.

[11] For a comparison between Marx and Schumpeter on capitalism's 'creative destruction' capabilities, see Elliot (1980).

[12] According to Lash and Urry (1994:5), the current phase of capitalism is characterised by a developing process of 'reflexive accumulation', as capital and its (re)production in innovation can be seen to emerge from greater socio-economic and political interaction between actors and individuals representing different aspects of society (Giddens, 1990). This argument is positioned within broader notions of reflexivity which have gained currency in the debates about change in modern society especially with regard to the emergence of a 'risk society' (see, for instance, Beck, 1992; Beck et al., 1994). **Section 7.5** considers the issue of 'reflexivity' in greater depth.

to be an integral aspect of modern society (Ihde, 1995).[13] Discussions about what science and technology are, and how they relate to each other, have been important to academics for a number of years (McKelvey, 1996:6). Considerable contention exists over whether science and technology should be considered as separate (Layton, 1976; Buchanan, 1994; Cardwell, 1994; Faulkner, 1994), or whether and to what extent they have merged into one (generally Nandy, 1988:3; for biotechnology Rabinow, 1996:10; Richards and Ruivenkamp, 1996). But it is generally accepted that in modern capitalist societies they are increasingly connected.[14] Many commentators argue that given current conditions of modern capitalism, the boundaries between science and technology have softened as new forms of capital accumulation have been sought (Latour, 1987; Menser and Aronowitz, 1996:7; Davis, et al., 1997; Haraway, 1997:3). Technoscience, therefore, emerges out of the linking of science and technology to industrial capitalism (Tiles and Oberdiek, 1995:111).[15]

Fourth, in its attempt at linking together science and technology, biotechnology is part of a wider strategy to maintain and promote capitalism (Buttel, 1998). The notion that biotechnology has become a major driving force for change and development in capitalism is articulated by many writers. One argument noted earlier centres on the emergence of a new techno-economic paradigm which brings about new technological and economic possibilities (Freeman, 1991; Fransman et al., 1995; Roobeek, 1995; Castells, 1996). From about the mid 1970s, it is argued that a transition from one phase of capitalism to another has occurred (Aglietta, 1979; Lipietz, 1987; Harvey, 1989; Amin, 1994). In a prosaic empirical sense, the new techno-economic paradigm is seen to tackle a number of 'control problems' inherent with the preceding phase of 'organised capitalism' (Lash and Urry, 1987), including the maturation of product life cycles, overcapacity

[13] It is important, however, to avoid reducing modern society to technology (and science) as characterised by, for instance, writers such as Marcuse (1986) in the Frankfurt School. Nevertheless, it is useful to understand it dialectically as technoscience influences, and is influenced by, modern capitalist societies.

[14] There is some issue over whether this connection is a relatively new phenomenon. For instance, according to Seitz (1992), science and technology were clearly linked at the beginning of the emergence of science. This issue is discussed further in **Section 2.3.**

[15] Quite apart from the blurring of boundaries between science and technology, technoscience can also be seen to exceed divisions between other dualisms, such as in relations between 'nature' and 'technology' (Harvey, 1996:280; Robertson et al., 1996:1; Haraway, 1997:3).

and market saturation, the increased importance of a diversified consumer demand, excessive dependence on non-renewable resources, rising wages and declining productivity (Roobeek, 1987 in Buttel, 1995:28). Biotechnology can therefore be seen to represent the basis of new forms of capital accumulation.

This brief presentation of the four 'tiers' does not exhaust the literature. But what the positions above point to is a need to take a step back from looking at biotechnological innovation purely in terms of the products and processes that are produced and the effects they have. Thus one of the ideas developed in this thesis argues that 'social' factors need to be understood as much as 'technological' ones in biotechnological innovation. Another idea explored is that linking in seemingly 'philosophical' reflections on science and technology to more grounded studies of the 'geographies' of innovation offers a useful approach to exploring the nature and characteristics of biotechnological innovation. From this position, an integrated approach to the study of biotechnological innovation which bridges some of the gaps and dualisms displayed in past studies - the hiatus between the micro sociological and the macro political-economy, the social and natural sciences, and the scientific and non-scientific, for instance - can be developed.[16]

1. 2 Research objectives

The principal aim of this thesis is to understand the general nature and characteristics of biotechnological innovation. As noted earlier, biotechnology covers a wide range of sectors. This thesis focuses on biotechnological innovation connected to agro-food systems. Agro-food biotechnology is clearly important.[17] In Europe, for instance, it has a market value currently of ECU 23 billion, 58 percent of the total biotechnology sector (Europabio, 1997:10). Moreover, many of the other

[16] The temptation to call this study multi-/inter-disciplinary is avoided because of a fundamental belief that much research that makes claims to bridge disciplines generally does so from a limited perspective. As a side issue, it is worth noting that frequently the hype of multi-/inter-disciplinary studies is linked to what public funding bodies are interested in seeing (Knights and Willmott, 1997).

[17] It is easy to forget, as some authors argue, that possibly the most important technological revolution is the one involving agriculture (Kealey, 1996:48); in fact, in some respects the transition from food collection to food production can be conceived as 'the' fundamental advance in technology (Derry and Williams, 1970:45; Diamond, 1998).

developments in this sector, such as chemical and environmental biotechnology, are closely tied to developments in agro-food systems. Most importantly, though, fundamental changes and developments are already visible in agro-food systems. Through the modification of genes, biotechnology is leading to plants and animals that resist diseases and pests, reduce environmental stresses, require less fertiliser or feed, and yield more food and fibre (Bills and Kung, 1992; EFB, 1994; MAFF, 1994; FDF, 1996a, 1996b; *Guardian*, 1997a, 1997b; *Science Museum*, 1997). Biotechnology is also at the centre of changes involving many of the key agents and organisational structures in agro-food systems including the (re)positioning of agriculture and the (re)fashioning of rural space (Munton, 1992; Byé and Fonte, 1994; Whatmore, 1994), the rearticulation of agriculture-industry relations and the emergence of a bio-industrial complex (Goodman et al., 1987; Goodman and Wilkinson, 1990; Goodman and Watts, 1994), changes in international competitiveness and trade flows (Junne, 1991, 1995; OECD, 1992), and the reconfiguration of production and consumption relations (Arce and Marsden, 1993). Finally, biotechnology promises to produce new and cheaper varieties of food and drink with better quality, taste and nutritional features (WHO, 1991, NCCPB, 1994; FDF, 1996b; FDF, 1998). These reasons for focusing on agro-food biotechnology notwithstanding, one further point needs to be made. In the UK, biotechnology has an 'actual' impact upon products (e.g. GM tomato paste, and GM soya) and processes (e.g. genetically modified enzymes [GMEs]) currently being used in the provision of food (*Guardian*, 1996a, 1997a, 1997b and 1997c; *Independent*, 1996a, 1996b; *Economist*, 1997a).[18]

A key reason for the focus in this thesis on agro-food biotechnology is that its impact can already be seen in the UK. But even if the processes by which these impacts come about is not limited by national boundaries, many of the products

[18] It is worth pointing out that studies on innovation have tended to avoid matters concerning agro-food systems (Friedland et al., 1981 in Kim and Curry, 1993; Buttel and Goodman, 1989; Ruttan, 1996). This tendency, according to some writers, is rooted in the belief that agro-food systems need to be treated as distinct and separate from other economic activities. For example, drawing on the work of Goodman et al. (1987; Goodman and Redclift, 1991), Fine and Leopold (1993) argue that because of food's 'natural' qualities it needs to be considered as a different and distinct socio-economic sector. Moreover, they believe that it is hard to generalise from aspects of agro-food systems to other forms of socio-economic activity. Whilst a detailed analysis of this argument is beyond the scope of this thesis, it is reasonable to suggest that there are differences in the take up of biotechnology depending on the particular sector it is being applied to.

and processes in agro-food biotechnology used in UK food provision do not originate here. In empirical terms, in focusing on the innovation of GMEs, this thesis cuts across a number of national contexts and boundaries. The 'spatial' implications of technological innovation in terms of both the geographical characteristics of the process and how capital is (re)produced and circulated are described fully elsewhere (from among many examples, see Harvey, 1989; Smith, 1990; Hilpert et al., 1991; Gregory, 1994; Schoenberger, 1997). Although the empirical work conducted here concentrates on particular national contexts - Denmark, the Netherlands and the UK, for instance - the 'geographies' of biotechnological innovation identified in this thesis are used primarily to understand the nature and characteristics of innovation in agro-food biotechnology. Thus following the notion that the dynamic nature of capitalist accumulation means that 'space' is always in a state of flux (Herod, 1997), when the theoretical foundations of this thesis are described and applied to the empirical data, the networks which are conceived as making up biotechnological innovation are treated as a particular spatial form (Cox, 1998). Put differently, the networks are seen to cut across broad and global concepts such as institutions, states and nations on the one hand, and notions such as the local and the global on the other, focusing more on smaller sets of relationships and associations (Latour, 1997a). In this respect, the account of innovation in agro-food biotechnology assumes a more complicated picture than research scientists working in university laboratories. Nor is the picture simply based on looking at firms and how and why they interact with other actors and institutions to develop agro-food biotechnology. It is about the different actors, activities and connections within and between them in the wider innovation milieu. Generally, then, this study is not primarily interested in identifying and analysing particular spatial dimensions to biotechnological innovation, but to use particular spatial forms to investigate how biotechnology comes about. In short, this study also looks at new ways for conceptualising and theorising (bio)technological innovation.

1.3 Research questions

In order to study innovation in agro-food biotechnology this thesis addresses two specific research questions. Whilst they are presented below in a

reasonably systematic fashion, it is important to recognise the interrelations between them.

(i) What are the main developments in agro-food biotechnology?

The purpose is to identify and analyse the main developments taking place in agro-food biotechnology. Despite the claims made about the 'revolutionary' potential of agro-food biotechnology, there is little clear evidence to suggest that this potential is being readily translated into reality. This basic question thus retains considerable significance.

(ii) How does innovation in (agro-food) biotechnology take place?

This question aims to identify and describe the main features of biotechnological innovation. The concern is to 'map' out some of the networks of biotechnological innovation. In particular, it investigates the connections and interactions between various 'social' and 'technological' aspects, some of the conditions of the environment in which innovation takes place, and the key actors and institutions that shape these arrangements and interactions.

1.4 Summary of thesis

The principal objective of this study is to identify and understand the general characteristics of innovation in agro-food biotechnology. This study analyses both the products and processes of agro-food biotechnology and the means by which they come about. In its simplest form, this thesis argues that as an increasingly important element of technoscience in modern capitalist societies, biotechnological innovation entails a multi-stable, diverse and ambiguous set of actors, activities and conditions whose ends are not readily predictable. Both major and minor features may arise for temporary local reasons but later become fixed and then predispose the context within which further innovation takes place. Furthermore, it will be proposed that (agro-food) biotechnology needs to be thought of as both an output and an input; that is, biotechnology creates, and is created by, biotechnological innovation. Finally, it is suggested that biotechnological innovation not only involves connections and interactions between

economic and technological factors but also entails cultural and existential exchanges.

This thesis is divided into two main parts. **Part I** provides the context and methods of research. In **Chapter 2** an analytical framework for examining biotechnological innovation is outlined. It starts by examining definitions of science and technology in order to both illustrate their importance for modern capitalist societies and the emergence of technoscience, and to highlight certain prevailing assumptions and ambiguities about how we view them and the relations between them. It also points to the need to not only look at biotechnological innovation in 'social' and 'technological' terms but also in terms of broader human-technology relations. Following this, drawing mainly upon approaches taken from economics and sociology, an overview of the main theoretical perspectives on technological innovation is presented. These approaches are seen to treat innovation from opposite vantage points - the macro political economy and micro sociological. In order to construct a more meso level approach, perspectives from actor-network theory (ANT) are developed and applied. Broadly, biotechnological innovation is conceptualised in terms of a network which ties in 'social' and 'technological' interests.

In contrast to the abstract contributions made in the preceding chapter, **Chapter 3** offers a brief overview of what biotechnology entails. In an attempt to provide a 'lay' person's account of biotechnology, this chapter describes how genetic modification, or recombinant DNA (rDNA) technology, has been developed and used.

In **Chapter 4** the main research techniques employed here to investigate biotechnological innovation are described. Questionnaire surveys and semi-structured interviews are used. The survey employs a postal questionnaire of research and development (R&D) managers involved in the production, consumption, regulation and stimulation of agro-food biotechnology in the UK. It aims to gather information on issues where little data existed including the following: the developmental trajectory of agro-food biotechnology; the nature of inter-organisational relations in biotechnological innovation; and the multi-/inter-

disciplinary nature of biotechnology. Furthermore, the questionnaire provides an opportunity to identify and evaluate some key concepts. The second and more substantial part of the fieldwork is organised around an in-depth investigation of the innovation networks of two GMEs - GM chymosin and GM xylanase. GMEs are arguably one of the most important developments in agro-food biotechnology with a real impact upon food provision in the UK. The investigation entails in-depth interviews and this chapter presents the main aspects of the interview-based research techniques used.

Having developed an analytical framework and outlined the empirical research techniques, **Part II** presents the data. **Chapter 5**, the first of three empirical chapters, addresses the first research question, 'What are the main developments in agro-food biotechnology?' Two different but connected dimensions to this question are addressed. The first identifies and describes some of the developments in agro-food biotechnology. Following this, in the light of differences in opinion on the specific nature of developmental trajectories in agro-food biotechnology, the second section re-considers conceptualisations of biotechnology based upon what individuals think biotechnology 'is' and how this impacts upon what developments are viewed as commercially viable.

Charting some of the 'networks' of biotechnological innovation is the aim of **Chapter 6**. Based on the specific study of innovation of GMEs, the chapter deals with the second research question, 'How does innovation in (agro-food) biotechnology take place?' Broadly, this chapter outlines some of the networks making up biotechnological innovation. But whilst this part of the research is organised around the study of innovation of two GMEs, it becomes clear that they are connected. Therefore, although only one account (in the form of seven stories) of biotechnological innovation is provided in this chapter, some of the particularities of the two examples are drawn out.

The final empirical chapter, **Chapter 7**, reinforces and extends some of the examples and arguments presented in **Chapters 5** and **6**. These two chapters focus on different aspects of the same phenomenon: biotechnological innovation as an output and an input. Behind the 'what' and the 'how' of innovation in agro-food

biotechnology is a view about knowledge and how it is created. Organised around the discussion of the multi-/inter-disciplinary nature of biotechnology, the relations between science and technology in biotechnological innovation, and the reflexivity of biotechnological knowledge, **Chapter 7** explores the nature of biotechnological innovation through an examination of knowledge and knowledge production.

Chapter 8 is a short epilogue. Given that the preceding empirical chapters draw out and discuss some conclusions on innovation in agro-food biotechnology, this chapter is more speculative. It presents an overall appreciation of the material in this thesis in relation to some of the ontological issues raised by the research. In particular, this chapter examines the ontologies of biotechnological innovation in relation to aspects of capital accumulation. The chapter then goes on to consider some of the contributions this thesis makes to (economic) geography. The chapter ends with some further questions and remarks about how the research can be taken forward.

2

CONCEPTUALISING (BIO)TECHNOLOGICAL INNOVATION

2.1 Introduction

Technological innovation is the focus of considerable academic interest. Not surprisingly, this interest has led to the development of many conceptual frameworks supported by a wealth of empirical studies. Here the purpose is to review some of the literature in order to construct an analytical framework for studying (bio)technological innovation within modern capitalist societies. Using perspectives from ANT to combine approaches from economics and sociology, the framework treats biotechnological innovation in terms of a 'network'.

This chapter is divided into four main sections. **Section 2.2** looks at the nature and characteristics of innovation. **Section 2.3** examines what 'science' and 'technology' entail, and the nature of the relations between them, especially in connection with the emergence of technoscience. In **Section 2.4,** theoretical schemes, drawing largely on research in economics and sociology, are reviewed to form the basis of an analytical framework. Other disciplines or areas of knowledge do not neglect technological innovation,[1] but social science thinking is dominated

[1] For example, research in management studies has examined technology learning strategies adopted by firms (Dodgson, 1991), the way technological innovations are organised and managed (Wheelwright and Clark, 1992), how managerial problems associated with innovation might be tackled (Burns and Stalker, 1994; Bower and Christensen, 1995), and the market uncertainties associated with technological innovations (Iansiti, 1995). In organizational studies, work has been carried out on the nature and structure of firms in economic activity (Winch, 1994), particularly in the food industry (Graf et al., 1991); and on the role of managers (Howells, 1994) and professional associations (Swan and Newell, 1995) in the development, application and diffusion of technological innovations. In recent years, innovation studies have taken a 'cultural turn' with work on the role of co-operation (Grant and Schlesinger 1995; Inkpen, 1996) and trust (Lane and Bachmann, 1996) in the innovation process, as well as how national cultures influence the development and application of strategic technologies (Shore and Venkatacalam, 1996). Elsewhere, there has been research on institutional arrangements and forms in high-technology industries, such as strategic alliance activity (SAA) (in biotechnology see, for example, Hagedoorn, 1993; Duysters and Hagedoorn, 1995; Prevezer and Toker, 1995). Finally, geographical interests traditionally have focused on innovation-diffusion and the social implications of technology (Hinchliffe, 1996). For instance, geographers have assessed the spatial distribution and organisation of R&D and production brought about by technologies (Massey, 1992; Kenney and Florida, 1993; Amirahmadi and Wallace, 1995;

by arguments made from these disciplines.[2] In **Section 2.5**, the macro-political economy and micro-sociological distinctions that emerge from the literature review are connected using ANT perspectives.[3]

2.2 The nature of innovation

Innovation is an ambiguous term. For example, Schumpeter's (1934:66) concept of innovation is a broad one and entails the:

> 'introduction of a new good....The introduction of a new method of production....The opening of a new market....The opening of a new source of supply....[and] The carrying out of the new organization of any industry, like the creation of a monopoly position.'[4]

Importantly for Schumpeter (in Freeman, 1987:7), a distinction between 'innovations' and 'inventions' needs to be made:[5]

> 'An *invention* is an idea, a sketch or model for a new or improved device, product, process or system. Such inventions may often (not always) be patented but they do not necessarily lead to technical *innovations*. An *innovation* in the economic sense is accomplished only with the first commercial transaction involving the new product, process, system or device, although the word is used to describe the whole process.' (italics in the original quote)

Behind this debate, however, are a number of key issues on the nature of innovation. For example, there is the problematic issue of distinguishing between

---

Florida, 1996) and the adoption and diffusion of technological innovations (Gertler, 1995; Alderman, 1998).

[2] It could be argued that the boundaries between these areas of knowledge are beginning to blur (for a general discussion, see Taylor, 1996). Recently, for instance, there has been a resurgence of links between economics and sociology generally (see, for example, Zukin and DiMaggio, 1990; Zukin, 1991) and especially in studies of technological innovation (see, for example, Coombs et al., 1992). That said, it is important to recognise that it was writers such as Marx and Schumpeter who first tried to integrate economics with sociology and economic history (Elliot, 1980).

[3] Two riders need to be added. First, most of the ANT literature does not address agro-food biotechnology and therefore my account is based on my interpretation and application of ANT. Second, although the research focus is on innovation in agro-food biotechnology, the framework developed here does, in some respects, set out a general scheme to explain technological innovation.

[4] Similarly, Rogers and Shoemaker (1971:19) argue that an innovation can be an 'idea, practice or material artefact'.

[5] Schumpeter's distinction between invention and innovation is maintained in current literature (see, for example, Betz, 1998:4).

'product' and 'process' aspects of innovation (Whipp and Clark 1986; Hippel von, 1988; Utterback and Abernathy, 1993; Ford, 1995; Slappendel, 1996). On a general level, 'innovation' can refer to both a 'process' and its 'result' (OECD, 1981). As the CEC (1996a:12; bold in the original quote) states:

> 'In the first sense of the term, **innovation process,** the emphasis is on the manner in which the innovation is designed and produced at various stages leading up to it (creativity, marketing, research and development, design, production and distribution) and on their breakdown. This is not a linear process with clearly delimited sequences and automatic follow-on, but rather a system of interactions, of comings and goings between different functions and different players whose experience, knowledge and know-how are mutually reinforcing and cumulative....In the second sense, **result of innovation,** the emphasis is on the new product, process or service. A distinction is made between **radical innovation** or breakthrough (for instance, the launch of a new vaccine, the compact disc) and **progressive innovation** which modifies the products, processes or services through successive improvement (e.g. the introduction of 32-bit chips to replace the 16-bit chips in electronic equipment, or the introduction of airbags in cars).'

Schematically, the product/process distinction can be presented in terms of whether what is developed or produced is an end in itself. The importance of realising this as an issue, however, lies in reasons for maintaining such a distinction. For Tornatzky and Fleisher (1991:20-21) three reasons can be identified for preserving this distinction. Firstly, although product and process dimensions are often complementary - that is developments in one area might drive changes in the other - the nature of this complementarity may change. In biotechnology, for example, the initial problem of preventing inserted genes from producing their expected characteristics (gene silencing) has now become a useful tool in its own right (Senior and Dale, 1996). Secondly, process technologies tend to be more systemic in their impact than products and, therefore, may have a greater impact. For instance, the use of rDNA technology in the production of GMEs has dramatically changed the way they are produced despite the fact that in physiological (and therefore in their application) terms they are similar to ones manufactured using non-GM technology (Pitcher, 1986; Teuber, 1993; Praaning, 1996).[6] Thirdly, the actors or interests associated with product and process innovations are frequently different. For example, there is evidence to suggest that

[6] The major difference between traditionally produced enzymes such as chymosin, often known as 'wild' ones, and GMEs are that the former are usually part of a cocktail of enzymes. This means that often in these 'cocktails' there are other enzymes which are not required or wanted. **Section 6.2,** provides a more thorough overview of GMEs.

in agro-food biotechnology, new relations between key actors involved in food provision are emerging which are changing the nature of agro-food systems generally (Goodman and Watts, 1994; Kenney, 1995; Ahson, 1996a). As Goodman and Watts (1994:30) write:

> 'This tendency is gathering further momentum as farmers and processors utilise plant and industrial biotechnologies to expand non-food markets for their output, including bio-fuels, chemicals and biodegradable industrial inputs. The rearticulation of agriculture-industry integration to exploit the potential of this emerging technological paradigm has been characterised in terms of a new 'bio-industry' complex.'

As noted in the previous quote from the CEC, innovation is seen to impact in two different ways: incremental and radical (Afuah, 1998:14). Incremental innovations modify only part of a process or product and their impact may be seen as limited (Freeman and Perez, 1988).[7] An example of an incremental innovation in biotechnology involves improvements in filtration techniques used in the manufacture of enzymes. Radical innovations may involve new products and processes that may have a more considerable impact. (ibid.). An obvious example of a radical innovation in biotechnology involves the use of rDNA technology. But as Lundvall (1992) points out, whether an innovation is incremental or radical can depend on the particular sphere it is affecting; for instance, an innovation may be technologically very advanced but have very little economic effect because it cannot be applied in particular products and processes.

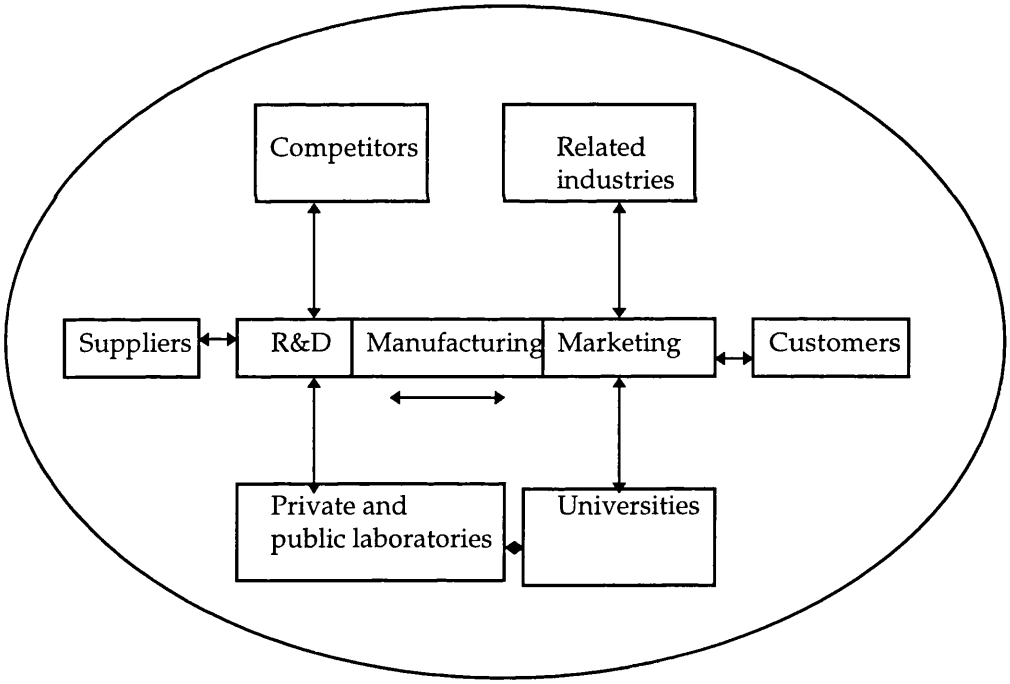
Innovation can also be viewed as taking place on different levels. For instance, it can be looked at in terms of the competitiveness of nations. Porter (1990) argues that innovation needs to be examined in terms of how different factors - labour and infrastructure; demand conditions such as the type of the domestic market; relevance of supply industries; firm strategy, structure and rivalry; and government policies, for instance - come together and interact. Innovation can also be viewed from a project level. For example, Hauschildt (1993) highlights the importance of different variables, such as product development strategies, importance of market focus, and the organisation of innovation processes, that influence innovations on their ways from the initial concept to the market place.

[7] Of course their cumulative impact may be large.

Finally, innovation can be considered on the level of the firm or organisation. The firm is considered by many writers to be the most useful level of analysing innovation (Teece, 1988; Alderman, 1998). The dynamic for innovation is seen to take place within firms (K. Smith, 1996; Randle and Currie, 1996) or sets of firms (Dicken and Thrift, 1992; Crewe, 1996) within a broader framework of capital accumulation. And whilst there are a range of external influences on innovation (see **Figure 2.1**), firms nevertheless are generally recognised to be the main unit for decision-making and profit seeking which shed light on how and why innovation occurs (Hall, 1994:167-72).

Figure 2.1: Influences on innovation

Regulation/deregulation *Technological change* *Customer expectations*



Globalisation *Political/legal* *Social/demographic*

Key: influences on innovation in bold and italics

Source: Afuah (1998:70)

In addition, innovation is a non-linear process: early models of innovation implied or even stated a simple sequential approach characterised by a number of functional phases such as product definition and idea generation, invention (prototype), research and development, application and diffusion (Kelly et al., 1989:25; Peters, 1992:730).[8] This view, sometimes known as the 'science-push model', was prominent among leading scientists; for example, the American Vannevar Bush noted that 'new products and processes are founded on new principles and conceptions which, in turn, are developed by research in the purest realms of science' (1945:19, in Hall, 1994:22) and can be shown diagramatically (see **Figure 2.2**) More recent work suggests that there is no simple linear logic to innovation as it is a 'recursive' process displaying a whole series of multi-directional circuits, exchanges and flows, involving individuals and objects (Tornatzky and Fleischer, 1990:30; Scarbrough and Corbett, 1992; CEC, 1996a; McKelvey, 1996; see **Figure 2.3**). Of course, it would be ill-informed to deny any linearity in the innovation process as final products and processes are produced. But innovation entails many activities and mechanisms working simultaneously.

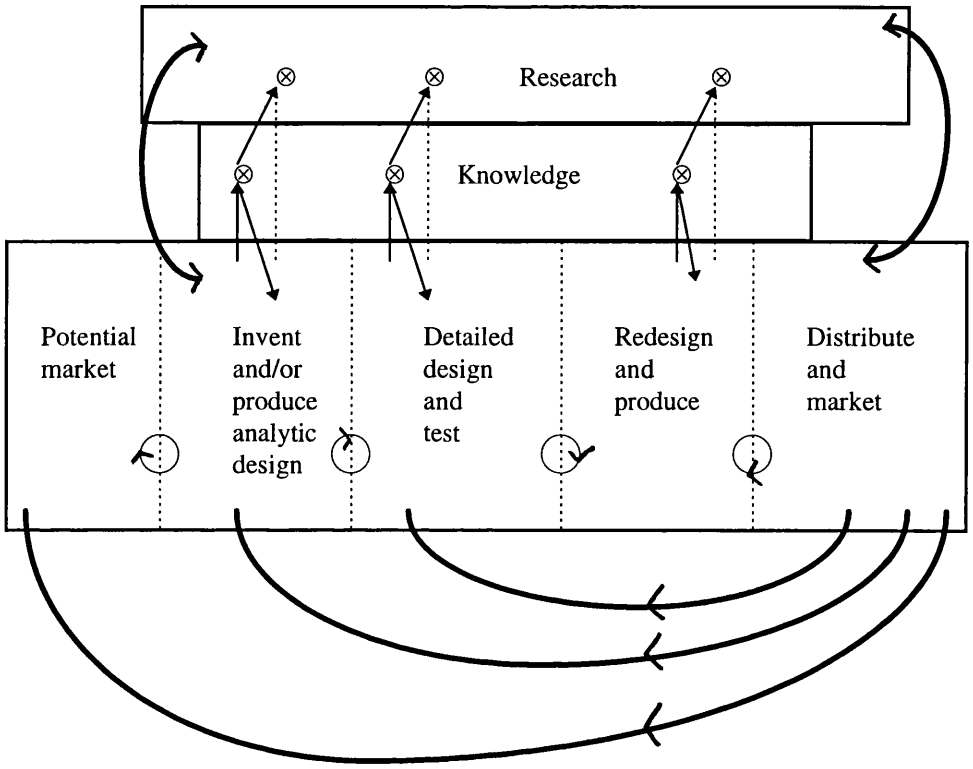
Figure 2.2: A linear model of innovation

basic	discovery/	applied	development	innovative
⇒	⇒	⇒	⇒	⇒
research	invention	research		product

Source: Randle and Currie (1996:80)

[8] There is an abundance of material seeking to describe technological innovation, but much of this work lacks theoretical analysis and is based on describing case studies. Not surprisingly, some of this material is often referred to as 'Heathrow Organisation Theory' (the type of literature typically found in airport and station bookshops which attempts to provide management guides) (Winch, 1994:4).

Figure 2.3: A recursive model of innovation (chain-link model)

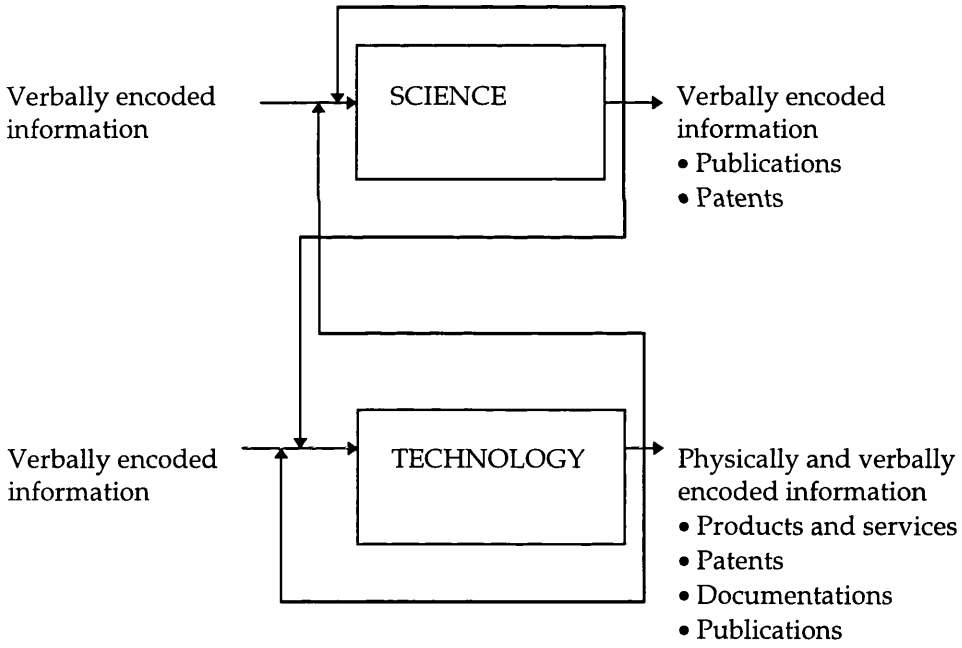


Source: Randle and Currie (1996:82)

Finally, innovation does not necessarily involve 'high' science and technology such as rDNA technology. Innovation covers a wide spectrum from 'blue-sky' research to product innovation and ranges from major technological advances to the informal exchange of knowledge and ideas (Smith, 1990:126). Nevertheless, the scientific and technological aspects are usually present and play an important part in innovation (Tornatzky and Fleischer, 1990:10). Indeed, it is reasonable to assert that in many instances, scientific and technological skills are essential if innovations are to be developed and used effectively (CEC, 1996a:13; Betz, 1998). As many writers on innovation such as Schumpeter (1976) argue, scientific and technological factors are the main dynamic in innovation. Evidently, this leads to the question 'what is the relationship between science and technology?' In abstract terms, three models for the relationship between science and technology can be identified (Afuah, 1998:84-85). The first is the unidirectional

model where basic science yields discoveries, which then lead to applied research, which, in turn, leads to inventions and commercialisation. The second model suggests that science and technology travel separate paths and they progress independently of each other. The third model, agrees with the first in that science can underpin technology, but it disagrees with the notion that the relationship is unidirectional as some technology is seen to influence developments in science. This last model seems to reflect current thinking on the relationship between science and technology as they are viewed as feeding off and complementing each other (see **Figure 2.4**). However, this model assumes a rather narrow, neat and detached view of what constitutes technology and science and the nature of the relations between them.

Figure 2.4: Relationship between science and technology



Source: Afuah (1998:86)

2.3 From technology and science to technoscience

Technology is said to have been around a long time: the notion *Homo fabers* (humans the makers) points to technology, in its simplest form as tools and objects,

as integral to society. As Ortega (1914, in Mitchum, 1994:47), one of the first writers to address the question of technology, remarks:

> 'This invented life, invented as the invention of a novel or a work of the theatre, is what a person calls human...and this a person makes himself beginning with the invention of it.'

On the face of it, it is reasonable to assert that there are no human cultures which are pre-technical as all cultures have some appreciation of material culture (Ihde, 1993:48-49). The word *technology* derives from the Greek words *techne*, an artefact - originally, something carved - and *logos*, thought or reason - that is, the study of something (Tornatsky and Fleischer, 1990:9). The word itself, however, seems to have been coined in the 17th century when according to some writers the foundations of 'modern' technology were established (Cardwell, 1994:107).[9]

As Grint and Woolgar (1997:7) point out, definitions of technology are seen to carry 'a huge array of conceptual baggage that colours our assumptions about its significance' (see also Winner, 1977:8). Derry and Williams (1970), for instance, argue that technology comprises the range of devices and knowledge through which humans are able to control their environments. Similarly, Buchanan (1994) notes that technology is the study of human techniques for making and doing things, and is concerned with understanding them within the environment of their social development. Winner (1977), more generally, shows that definitions of technology have changed over time and place; for instance, technology for the ancient Greeks meant the practical arts as opposed to science or even art itself. For Kaplinsky (1984), it is important to distinguish between 'technology' and

---

[9] Of course the word technology has different meaning in different languages. According to Mackenzie and Wajcman (1996:24), in French or German *la technique* or *die Technik* is normally written. But as Saloman (1984:113 in ibid.) notes, '[O]n the Continent, in French, German or the Slavic languages, *la technologie* seems redundant beside *la technique* which covers all activities associated with things technical; *technologie* is much more specialised and refers to more advanced stages of technique. English has no real equivalent of *technique* and uses "technology" to cover what on the Continent would be both *technique* and *technologie*.' Whilst there have been some attempts to introduce this distinction in English, such as by Mumford, generally this distinction has not been successful (Mackenzie and Wajcman, 1996:25). For this thesis, given that much of the data were gathered outside the English-speaking world, this question about definitions could have important implications. That said, during the course of the fieldwork, on matters concerning 'biotechnology' the English usage prevailed (see **Chapter 4** for a discussion of the research methods used in this study).

'technique': the former referring to the general material content or process, the latter referring to the way in which the general technology is developed for a specific purpose.[10] Technology, therefore, can be defined and interpreted in different ways. Usefully for this thesis, Ihde (1993:47) outlines three key aspects of technology:

> 'First, we shall insist that a technology must have some concrete component, some material element, to count as technology...second, a technology must enter into some set of praxes - "uses" - which humans make of these components. And third, we shall take as part of the definition, a relation between the technologies and the humans who use, design, make or modify the technologies in question.'[11]

Overall, then, a broad definition of technology which encompasses the concrete material and knowledge aspects seems to be more appropriate for understanding its role and importance in society. Consistent with virtually all of the above definitions and interpretations, however, are the links made with 'science' (see, for instance, Cardwell, 1994:1-5). According to Russell (1954:10-11), science is:

> 'primarily knowledge; by convention it is knowledge of a certain kind, the kind, namely which seeks general laws connecting a number of particular facts...however, the aspect of science as knowledge is being thrust into the background by the aspect of science as the power of manipulating nature.'

For many writers, this attempt at controlling nature is said to find its roots in the emergence of the methods and philosophical concepts of the 'scientific vision' which emerged in Europe in the 17th century, and which were organised around the desire to improve human conditions (Chalmers, 1988:xvii; N. Smith, 1996:39; Gower, 1997).[12] For example, Francis Bacon in *Novum Organum,* sets out his conception of the scientific method: it involves the collection of particulars through

---

[10] As highlighted in **footnote 9** in this chapter, there is some danger of confusing technology with technique. I use the word technique to refer to the knowledge and expertise to apply technology. Having said that, some authors use them interchangeably.

[11] Many definitions of technology are said to be characterised by the attempt to distinguish between its human and non-human elements (Grint and Woolgar, 1997:9). But increasingly this dichotomy is seen by some writers to be difficult to sustain. Hughes (1987) has proposed a unity between human and non-human aspects through connections in a 'web' or 'network'. As will be pointed out in **Section 2.4.2**, this perspective has important consequences both for the conceptualisation of (bio)technological innovation and the research techniques employed to examine it.

[12] Behind all this, however, is the fundamental issue briefly highlighted in **Chapter 1**, namely that science, the scientific vision and technology have together played an important role in creating and sustaining the project of modernity.

observation and systematic experimentation, putting down these data in writing in well arranged fashion, and deriving axioms which could confirm their own extent and generality (Bajaj, 1988:25).[13] As with Aristotle, Bacon's 'inductive' method entails the collection of information through observations followed by the making of generalisations (Richards, 1987:46). Critically, his way of 'doing science' emphasises the role of experiments as a means to 'reveal the truths nature would otherwise conceal' (Gower, 1997:46).

Ostensibly, from the account above, science appears to be different from technology. According to Buchanan (1992:7), science and technology represent completely different entities: science is concerned with the systematic understanding of men and women in their environment, whereas technology is concerned with making and doing things. Cardwell (1994:486-491) is of the view that the main difference between science and technology is rooted in the notion of purpose: many advances in science, such as Dalton's atomic theory, have been made by scientists whose original objectives were quite different from their ultimate objectives; by contrast, technologists or inventors work generally towards a foreseen objective. For Kealey (1996:24), technology is the activity of manipulating nature whereas science is the activity of learning about nature. He proposes that each employs the same method (the scientific method of systematic observation, hypothesis and experimentation) but each is different in purpose. Thus to take another example, a technologist might aim to test different alloys for their durability as components of knives, whereas a scientist might be concerned with understanding the molecular basis for different metals (ibid.). Finally, for Betz (1998:77) science is a set of activities 'about' nature and is not directly useful for the economy; instead, it is indirectly useful through technology because the economy needs to 'manipulate' nature.

But the distinction between science and technology is not as simple as the preceding discussion suggests. This is especially apparent when considering their

[13] As an aside, some writers have emphasised the importance of 'geography' in the scientific revolution. For instance, Livingstone (1992: Chapter 3) notes that key social movements during the time of the scientific revolution in Europe, such as hermeticism, Reformation theology, Puritan social policy, overseas expansion and the art of map making, had a profound effect on the development of geographical knowledge and vice-versa.

relationships. Laudan (1995) identifies three competing and contrasting notions of the relationship of technology to science. The first, which emerged in the 1950s and 1960s, and was born under the banner of positivism, treats 'technology as applied science' (ibid.:18). Apart from a few exceptions, such as the relations between astronomy and navigation, the first applied sciences were the chemical and electrical sciences of the 19th century which encouraged the development of the dye and pharmaceutical industries; prior to this it was argued that science and technology were entirely separate enterprises and it was simply a coincidence that they began to be connected in the 17th century. Laudan's second view treats technology as the mirror image of science; that is, like science, technology had its own institutions, its own values and methods, and its own kind of knowledge (ibid.:19). In this case, a whole series of relationships or multiple connections between science and technology can be identified which are not simply a matter of the former being applied to the latter. Third, Laudan outlines the view of technology as the means of gaining a given end (ibid.:20). For example, many of the industrial applications of 'Newtonian science' had been promoted by Newton and his followers.

For the ancient Greeks, science was not experimental in any real sense of the word even though it was seen to be a time of great technological and experimental development (Ihde, 1993:6-7). In fact, in philosophical terms, the ancient Greeks were seen to enforce a separation between 'science' and 'technology' (Vazquez, 1977:13-14). Added to this, all the technological developments achieved by the ancient Greeks appeared to be destroyed during the 'dark ages' leaving the major technological advances to be made in the Islamic world.[14] During the 17th century, however, a much closer relationship between science and technology began to

[14] I am acutely aware of the bias in this description of science and technology with regard to its 'geography' (read: Eurocentrism). Whilst the ancient Greeks are conventionally considered to be the founders of science, they were certainly not the only ones involved in this activity. For example, Joseph Needham, in his investigation of Chinese science, came to the conclusion that during the time of the ancient Greeks, Chinese culture was much more efficient in applying human knowledge to practical human needs (Bajaj, 1988:54). In a slightly different vein, Pacey (in Buchanan, 1992: 35) points out that the history of technology has been one of a dialogue or dialectic between different 'cultural' traditions in the world. Of course, it can be argued that it is the 'European' culture of science and technology that has developed and spread throughout the world. The point I want to make here is that conceptions of science and technology may differ around the world; that is, they are not value-neutral.

emerge. Galileo for one was among the first Europeans to promote a 'technologically embodied science' in his use of instruments for experimental purposes (Dosi, 1988:1136; Ihde, 1993:25); for some people Galileo was known as 'the father of experiments and all their exactness' (Drake, 1978:367, in Gower, 1997:23). As science and technology have increasingly been seen to be connected, some writers suggest that a blurring of boundaries has taken place between them (generally Nandy, 1988:3; for biotechnology Rabinow, 1996:10; Richards and Ruivenkamp, 1996). Latour (1987:174-75) goes as far as to argue that the distinction between science and technology itself is too neat as the boundaries between them have 'become obscure to the point of irrelevance'.[15] Other writers argue that under modern capitalism, the boundaries between science and technology have fused in the search for new forms of capital (Vazquez, 1977:17; Latour, 1987; Menser and Aronowitz, 1996:7; Haraway, 1997:3). Technoscience,[16] therefore, connects science and technology to industrial capitalism (Tiles and Oberdiek, 1995:111; Dickens, 1996:45).[17]

Despite the view of an increasing interconnectedness or blurring of boundaries between science and technology, there remain various interpretations about relations between them and whether they can be interpreted as distinct entities. Common to many of these interpretations is a sense of a hierarchy or preference. Two opposing aspects of this are important here. On the one hand, it is argued that technology owes much to science. For example, the implicit knowledge associated with *techne* was downplayed by the ancient Greeks, as science was seen to precede technology (Vazquez, 1977:11; Ihde, 1979:xix).[18] On the other hand, technology is seen as having a longer history than science and therefore came first (Kealey, 1996:24). According to Seitz (1992:8), for instance, technology in the form of

---

[15] Interestingly, this is a feature emphasised in many descriptions of biotechnology (see, for example, OECD, 1989).

[16] Whilst Latour (1987:29) claims to have forged the term technoscience, according to Ihde (1993:143) it may have originally been coined by Bachelard in the 1930s. A further point to bear in mind is that technoscience is used in the singular in this thesis for the purposes of consistency, and few examples of it being used in the plural can be found in the literature.

[17] Despite the growing agreement on the emergence of technoscience, it is difficult to be explicit over its periodicity. In general terms, it can be connected to developments in this century when the generation and use of scientific knowledge is internal to developments in technology (Dosi, 1988). Most authors who use the term technoscience are not specific about when it emerged.

[18] Not surprisingly, apart from a couple of inventions associated with warfare, the ancient Greeks were not especially strong in technology (Ihde, 1993:23).

'common sense reasoning and trial and error' carried many societies to the Industrial Revolution. Thus he argues that the birth of science could not have been possible without significant prior advances in technology (ibid.:10).[19] On the face of it, it would be wrong to suggest that the stark dichotomy posed by these opposing views cover all possible positions on how science and technology are connected to each other. Nevertheless, the hierarchy associated with these views is a dominant feature of relations between science and technology.

There is, however, a further dimension to looking at relations between science and technology. Technoscience is not only about products and processes, but also involves existential connections with human society. Technoscience is non-neutral and deeply embedded in daily life practices (Ihde, 1995:12). For Heidegger (1977:4), the essence of technology is not technological but existential and, therefore, technoscience needs to be considered in terms of relations with human society. At the heart of the essence of technoscience are relations between 'science' and 'technology'.[20] For biotechnology, the connections and interactions between 'scientific' and 'technological' elements are critical (Kloppenburg, 1988; Green, 1992; Tiles and Oberdiek, 1995; Randle and Currie, 1996). Despite the identifiable sense of the softening of boundaries between them, what is also apparent from the literature

[19] More specifically, Kranakis (1990) identifies a number of different ways in which technology has influenced the construction, evaluation and acceptance of scientific knowledge. Briefly, the six principal contexts of influence are through: technological artefacts or systems viewed as heuristic models or analogies; artefact theories; technoscientific research; instrumentation; the political economy of technology; and the social-institutional contexts of technological activity (ibid.:134).

[20] There are several existential aspects to biotechnological innovation. For example, it can involve the notion that technology (and science) determine the development of human societies. This view is a form of technological determinism which leaves little scope for the role of the individual or agency (see Pepper, 1996:91). Technology (and science) are clearly powerful agents of social change (M. Smith, 1994:2; Castells, 1996:5), and according to Ellul (1965), technology is the most important societal phenomenon of the modern world. Fundamentally, Ellul (1965, in Giddens, 1990:170) is of the opinion that technological innovation is characterised by an inner dynamic. Ellul's position can be placed at the 'hard' end of the technological determinist's spectrum, as agency (the power to bring about change) is ascribed in technology itself. At the other end of the spectrum, a 'soft' determinist's interpretation suggests that the history of technology is a history of human actions (Marx and Smith, 1994). Therefore, instead of treating technology as the locus of historical agency, the 'soft' determinists locate it far more in the matrix and complexity of cultural, economic, political, scientific, social and technological relations. Most recent historical and sociological perspectives on technological innovation treat technologies as 'social' constructions as much as 'technological' ones (Mackenzie, 1992:34; Mitchum, 1994:60; Grint and Woolgar, 1997:14). Technological determinism is increasingly regarded as an untenable position.

is that the simple 'technology is applied science' view remains pervasive (Mitchum, 1994:197). For example, Kline (1995) argues that in the United States many prominent engineers and industrial researchers consider and promote their work in terms of 'applied science' because of the augmentation of status that is associated with this conception of it. Similarly, Kealey (1996) is of the opinion that in modern capitalist societies, the view of 'technology as applied science' is reinforced by models used in the promotion of science and technology. For example, one model promoted by Francis Bacon was premised on the belief that science led technology and therefore science needed to be promoted by governments through universities and academic institutions (ibid.:3-5); another model proposed by Adam Smith suggested that technology could be largely derived from the industrial development of pre-existing technology which, in turn, would spawn science (ibid.:8-9). Critically, governments and government institutions have tended to adopt Bacon's linear model (ibid.:303; K. Smith, 1996).

The logic of such a standpoint is rooted in the 'ontological' priority science is given over technology in modern capitalist societies.[21] As described earlier, the ancient Greeks downplayed the implicit knowledge associated with *techne*. Leaving aside an in-depth review of the philosophical basis to this tendency among the ancient Greeks (for which, see Russell, 1979), their position was mainly influenced by Aristotle's views on metaphysics and logic. Aristotle argued that natural phenomena can be examined through a 'deductive' method which entails using argument and logic independent from experience (Richards, 1987:44; Trigg, 1993:14), and proposed a system which centred on devising statements (syllogisms) which would lead back to facts or conclusions about the world. Unfortunately, as Richards (ibid.:45) points out, Aristotle does not say how such questions are to be answered and, more especially, there is no suggestion as to the use of experiments. This lack of comment on experiments links back to the contempt the ancient Greeks

[21] For Tiles and Oberdiek (1995:4) a further indication of this hierarchy of science can be found in philosophy. Although the growth of science was paralleled by the emergence of a strong tradition in the philosophy of science in the 19th century, developments in the corresponding technology did not generate a philosophy of technology, although the roots of a philosophy of technology can be found in the work of the German philosopher Ernst Kapp (1808-1896). Kapp, like Marx, was a left-wing Hegelian and sought to translate Hegel's dynamic idealism into firmer materialist terms (Mitchum, 1994:21). But whereas Marx's materialism aimed to link Hegel's theory of history to economics, Kapp sought to relate history to Ritter's new science of geography (ibid.).

held for practical activities. Perception or experience are seen to be on a lower scale of human activity than what is presumed conceptually, a notion central to the myth of the cave in Plato's *Republic* (Ihde, 1979:xix-xx; Vazquez, 1977). Taking this notion to its logical conclusion, it becomes evident that any hypothesis, however absurd, may be useful in science if it enables a discoverer to conceive new things in a new way (Russell, 1979:146). Behind all this, is a clear distinction between *theory* and *praxis*[22] in the Platonic tradition (G. Smith, 1996:269).

This primacy of theory over praxis entered a new dimension in the 16th century with the work of Bacon and Galileo. Whilst building on the Aristotelian ideas of the deductive method, they (relatively simultaneously) developed the method in relation to the role of experiment as a new means of exploring the world (Chalmers, 1988:1; Gower, 1997:21). As with Aristotle, Bacon not only shared a preoccupation with the collection of information about the world but also neglected to offer convincing examples of this method in use (Richards, 1987:46). But whilst Bacon's work is an example of science becoming more conscious of technology, in historical and philosophical terms his work remained second to the more theoretically minded Descartes (Ihde, 1993:22-23). Descartes, through his 'geometrical method' and deductive forms of argument, disliked instruments and technology because he felt they failed to deliver the precision of deduction. The dominant strands in philosophy tended to read Descartes over Bacon leading to a neglect of the technological side to the scientific method (ibid.; Vazquez, 1977:22).[23]

This ontological priority given to science over technology has not remained unchallenged as a number of philosophers have taken the issue of technology and praxis seriously. Heidegger is one of the first to raise technology to a central concern for philosophy (Ihde, 1979; Zimmerman, 1990; Dreyfus and Hall, 1992; Cooper, 1996; G. Smith, 1996), He argues that there is a technological way of doing

---

[22] According to Vazquez (1977:1), the ancient Greeks used the word *praxis* to denote action itself. In English, he suggests the word *practice* is often used while *praxis* is seen to have a limited philosophical status. Borrowing from Vazquez, I use praxis because it is freed from the associations of everyday life and allows a philosophical conception of action to be undertaken. This is especially useful when thinking about the ontological elements of (bio)technological innovation (see **Chapter 8**).

[23] This is often translated in terms of the Cartesian separation between mind and body. According to Harvey (1996:48), this separation is a key element of our current epistemology-cum-ontological framework.

and seeing things, and that scientific knowledge - contrary to the dominant position of the time - is a derivation from and dependent upon a more primitive praxical knowledge (Heidegger, 1977:xxvii; Ihde, 1993:38-40). With Heidegger, the praxical takes ontological priority over the theoretical, and everyday experience take priority over scientific cognition (Fell, 1992:66). Therefore, for Heidegger (1977:14), in ontological terms technology precedes science:

> 'It is said that modern technology is something incomparably different from all earlier technologies because it is based on modern physics as an exact science. Meanwhile we have come to understand more clearly that the reverse holds true as well: Modern physics, as experimental, is dependent upon technical apparatus and upon progress in the building of apparatus.'

Of course for Heidegger, 'technology' has a far broader meaning than the definitions outlined earlier (Lovitt, 1977; Vattimo, 1988:29; Cooper, 1996:63). According to Zimmerman (1990:xiii), (modern) technology for Heidegger has three interrelated meanings:

> 'first , the techniques, devices, systems, and production processes usually associated with *industrialism*; second, the rationalist, scientific, commercialist, utilitarian, anthropocentric, secular worldview usually associated with *modernity*; third, the *contemporary mode of understanding* or *disclosing things* which makes possible both industrial production processes and the modernist worldview' (italics in the original quote).

Heidegger maintains that this third meaning of technology is the most important as both industrialism and modernity are symptoms of, or are governed by, this way of 'revealing' (ibid.; Cooper, 1996:64).[24] He argues, following a line developed from Hegel, that modernity is never a final term for explaining the contemporary situation but rather a symptom of a deeper movement that is hidden from view (Zimmerman, 1990:xiv). This movement began with Plato's metaphysics (translated by Aristotle) and culminated in the current technological era. Furthermore, he suggests that the major periods in Western history - Greek, Roman, Medieval, Enlightenment, technological - mark stages in the decline of the modern capitalist societies (ibid.). For Heidegger, then, 'The Question Concerning Technology' is

[24] Thus as Heidegger's student Habermas (1992:195) notes, 'in the context of a history of metaphysics, "technology" is the expression for a will to will, which in practice makes itself felt in the phenomena of positivistic science, technological development, industrial labour, the bureaucratized state, mechanized warfare, the management of culture, the dictatorship of public opinion, and generally urbanized mass civilization.'

part of a wider concern about 'being' and how the metaphysics of the ancient Greeks has degenerated into modern technology.[25] Here the detached superiority of the scientist is seen to become the model and grounds for existence (Waugh, 1992:2). And unsurprisingly, Heidegger feels that technology dominates 'man', and that it will produce uncontrollable results. Commenting on the potential of biotechnology, Heidegger (1966:52) writes:

> 'We do not stop to consider that an attack with technological means is being prepared upon the life and nature of man compared with which the explosion of the hydrogen bomb means little. For precisely if the hydrogen bombs do not explode and human life on earth is preserved, an uncanny change in the world moves upon us.'[26]

The purpose of highlighting the work of theorists such as Heidegger is to emphasise a deeper existential dimension to technoscience and biotechnological innovation specifically. As well as thinking about the products and processes making up and coming out of technoscience, it is important to recognise that they are conceived and constructed through the experience of their use in broader

---

[25] A further dimension to this failing in Western metaphysics is what Bhaskar (1993:74, 1997) calls the 'epistemic fallacy' whereby statements about 'being' are transposed into statements about our 'knowledge of being'. But as Bhaskar (amongst others) argues, ontology cannot be reduced to epistemology (ibid.).

[26] This pessimism with technoscience is shared by a number of other writers. For example, Ortega rejects the definition of 'technology being applied science' and views too much technology as a danger (Mitchum, 1994:55). Furthermore, he argues that the projection of technology is not a 'natural' or 'organic' activity but rather a rupture with the natural world as 'human beings are technical, are capable of modifying their environment to fit their sense of convenience because they take advantage of every respite that things allow in order to retire within themselves, to enter into themselves and form ideas about the world, about things and their circumstances, in short, to construct an inner world. From this inner world they emerge and return to the outside. But they return...with *selves* they did not have before...in order to impose their wills and designs, to realise in the outside world their ideas, to mould the planet according to the preferences of their interiority' (1957, in Mitchum, 1994:56; italics in the original quote). Unfortunately, it is not clear what Ortega means by 'natural' in this case. Drawing on a Marxist heritage, members of the Frankfurt School argue that technoscience hides a form of dominating political power. For example, Marcuse, who also looks at technology in terms of the ontology of practice (Feenberg, 1995), believes that as 'a technological universe, advanced industrial society is a *political* universe, the latest stage in the realization of a specific historical *project* - namely, the experience, transformation, and organization of nature as the mere stuff of domination. As the project unfolds, it shapes the entire universe of discourse and action, intellectual and material culture. In the medium of technology, culture, politics, and the economy merge into an omnipresent system which swallows up or repulses all alternatives. The productivity and growth potential of this system stabilize the society and contain technical progress within the framework of domination. Technological rationality has become political rationality' (1986:xvi; italics in the original quote). As an aside, Touraine (1995:147) notes, that the Frankfurt School reduce the entire project of modernity to technology; that is, they essentially take a technological determinist stance (see **footnote 20** in this chapter).

human-technology relations. In this respect, understanding technoscience needs to go beyond thinking about how the 'social' shapes the 'technological' and how the 'technological' shapes 'society'; it is also important to consider how technoscience is already part of the essence of society.

2.4 Conceptualising technological innovation

Technology, science and technoscience are clearly important features of modern capitalist societies and certainly warrant further research. Equally, there is a growing need to increase understanding of the complexity of innovation. The important question in the context of this thesis is explaining how (bio)technological innovation takes place. On an abstract level, there are two main categories of explanations for technological innovation (Slappendel, 1996). The first assumes that individuals are the major source of innovation. Individuals are seen to be self-directing agents motivated by their own particular aims. The second seeks to explain innovation in terms of structural conditions. Although the significance ascribed to these two categories varies among commentators, many phenomena associated with these abstract categories are apparent in studies of innovation.

Behind these explanations is the more fundamental question of the role technological innovation plays in modern capitalist societies. From the literature, it is easy to think that innovation is about the market strategies of firms. For example, Vergragt et al. (1992) examine the interrelationships between innovation, organisational structure and the external environment of firms. More recently, Afuah (1998:ix) explores the competitive advantage gained and maintained by firms through innovation. But by concentrating on firms there is a danger that the broader significance of innovation is ignored. According to a number of writers, technological innovation is part of a broader dynamic process of change and replacement that is the source of both instability and growth in capitalist societies (K. Smith, 1996:108; see also **Section 1.1**). Mindful of the broader significance of technological innovation for modern capitalist societies, some perspectives from

economics and sociology currently used to examine and explain technological innovation are outlined below.[27]

2.4.1 Economic perspectives

In some respects, economic perspectives on technological innovation are limited in approach. Neo-classical explanations of technological innovation treat it as exogenous to the economic system (Nelson and Winter, 1977, 1982; Coombs et al., 1987, 1992; Freeman, 1990). That is, the generation of new technologies is seen as independent of economic factors even though its impact upon economic variables such as productivity and prices can be considerable. Among 18th and 19th century economists, Marx and Smith combined an interest in the fundamental mechanisms of capitalist society with an analysis of how technological change itself was taking place. For Marx, during the development of the forces of production, one of the most important features is the transformation of the means of production into fixed capital in the form of the machine. Here the material modes of production are shaped to some extent by technologies (Ihde, 1993:30),[28] but for Marx, technology remains an exogenous factor.

This position was challenged in the first half of this century, prompted in part by the questioning of the notion that firms or economic units act in a rational manner.[29] Schumpeter (1934:80) observes that the:

---

[27] To reiterate a point made earlier, I limit my discussion to a selected group of contributions from economics and sociology and focus on how they can be combined to provide a basis for a new approach to investigating biotechnological innovation.

[28] Marx's views on the link between technology and productive power have been widely debated. Bimber (1994:96) proposes that Marx's description of the role of technology is not a description of a process which is dependent on technology but rather of certain characteristics such as the drive to accumulate and the resistance to alienation. Fundamentally, a question is raised about whether Marx's work can be construed as technologically deterministic. Whilst beyond the scope of this thesis there appears to be little agreement on this issue (see Miller, 1984:174-81, for a brief review of some of the arguments on whether Marx's work can be thought of as technologically deterministic).

[29] It is also useful to note that the challenge to the exogenous treatment of technology by neo-classical economics is mirrored in a broader 'crisis of confidence' in economics. Indeed, the universal assumptions - economic behaviour is intrinsically the same everywhere - is increasingly seen as untenable (Gamble, 1996:1935). In recent years, one of the main challenges to this view has come from 'within' economics over matters concerning international trade and strategic trade theory (see Ahson, 1994; Krugman, 1996).

> 'assumption that conduct is prompt and rational is in all cases a fiction. But it proves to be sufficiently near to reality, if things have time to hammer logic into men. Where this has happened, and within the limits in which it has happened, one may rest content with this fiction and build theories upon it....Outside of these limits our fiction loses its closeness to reality. To cling to it as the traditional theory does, is to hide an essential thing and you ignore a fact which, in contrast with other deviations of our assumptions from reality, is theoretically important and the source of our explanation of phenomena which would not exist without it.'

Schumpeter's work is arguably the single most important source on issues to do with innovation. Although open to widespread interpretation, according to K Smith (1996:108) three ideas central to his work need to be considered:

> 'Firstly, that competition in industrial economies is primarily technological - firms compete not in terms of the efficiency with which they produce given products, but rather by changing products and processes. Secondly, that this dynamic process of change and replacement - 'creative destruction' - is the source of both instability and economic growth in industrial economies. Thirdly, that the generation and management of such change is the primary internal problem in the modern corporation.'

Broadly, Schumpeter emphasises the importance of innovations as stimuli to economic growth (Coombs et al., 1987:4; Hagedoorn, 1994). Furthermore, in a radical departure from neo-classical economics, he suggests that the disequilibrium or 'the gale of creative destruction' which this situation brings about is the essential ingredient of capitalist economic development (Coombs et al., 1987:94; McKelvey, 1996:5).[30] Schumpeter did not study the specific features of innovation in any great depth (Freeman, 1991:76), but he highlights the importance of technology as the *modus operandi* of competition between firms (Schumpeter, 1976:84).

Following Schumpeter, from about the 1960s onwards, a number of detailed studies on technological innovation were conducted looking, in particular, at what made a successful innovation (Coombs et al., 1992:3).[31] But whilst these

---

[30] Explicit in Schumpeter's 'creative destruction' thesis is the notion of 'long waves' in technological innovation. Generally this notion can be traced to Kondratieff, a Russian economist, who proposed that capitalist economies are characterised by cycles or waves of economic expansion and contraction. He identifies three cycles, centring around the industrial revolution in Britain, industrial expansion in Europe and the imperialist expansions of Britain, Germany and the US; a fourth cycle is said to have taken place during the international recession of the 1970s and 1980s. Whilst the extent to which these cycles are causes or effects of capitalist development is a matter of debate, he does suggest that the mechanism for triggering these cycles of economic activity is technological development (Healey and Ilbery, 1992:15).

[31] See, for example, Jewkes et al. (1969).

studies contribute enormously to our understanding of the innovation process, they are deficient in two areas: firstly, they are still mainly anecdotal, and because their empirical bias concentrated on specific industrial sectors, they face problems when it comes to drawing out comparisons or generalisations; and second, they do not satisfactorily incorporate a number of institutional features which characterise modern capitalism (Coombs et al., 1987; Freeman, 1991). In an attempt at framing these empirical studies, some researchers are keen to up-date the Schumpeterian[32] approach to economic change and the role of technological innovation. A number of accounts of these 'evolutionary approaches', as they are often known, have emerged.[33] For example, Nelson and Winter (1977; 1982) link the evolutionary principle in economic terms to technological change leading to 'technological trajectories'. Not unlike genes, they argue that the regular and predictable behaviour patterns of firms, especially those that pass on information and skills, are 'routine' (1982:14). Importantly, they suggest that 'skills, organisation, and technology are intimately intertwined in a functioning routine, and it is difficult to say exactly where one aspect ends and another begins' (ibid.:104).

A more radical interpretation of evolutionary economic approaches is offered by Perez (1983) and Dosi (1982) who examine economic change in terms of

---

[32] As Buttel (1995:26-27) points out, these new theorisations continue to bear considerable similarity to the work of Schumpeter. Some of the most important 'neo-Schumpeterian' premises are maintained. They are: the origins of technological change are thought to lie in the 'heroic entrepreneur' who takes risks in implementing innovations in return for high profits; technological change is regarded as discontinuous in nature, representing decisive breaks with the past; technological change occurs initially through the clustering of major innovations in one or a limited number of sectors; technological change is a process of 'perennial gales of creative destruction' in which innovations in an ascendant sector lead to the obsolescence and decline of other technologies; these gales of destruction create giant discontinuities with, or disruptions of, past social arrangements; and current high technologies (like biotechnology) will be 'revolutionary' or epoch making.

[33] These evolutionary approaches draw part of their inspiration from neo-Darwinian theories of the selection of biological characteristics. The basic characteristics of neo-Darwinian theory include the following: the underlying evolutionary process is timeless and all organisms are descendants of one or a few simple organisms; the mechanism for evolutionary change is natural selection; and organic evolution is larger than natural selection and increases in their random genetic mutations (Mayr, 1982). That noted, in recent years there has been some debate over whether Schumpeter's approach is really evolutionary (McKelvey, 1996). For example, some writers such as Andersen (1994, in McKelvey, 1996:5) argue that Schumpeter is evolutionary because of his emphasis on dynamics. By contrast, Hodgson (1993, in McKelvey, 1996:5) suggests that Schumpeter's view of evolution differs greatly from biological versions. Nevertheless, the 'evolutionary' principle is still popular in studies of technology.

shifts in the dominant 'techno-economic paradigm'.[34] According to Freeman (1988:10) a techno-economic paradigm is:

> 'a cluster of interrelated technical, organizational, and managerial innovations whose advantages are to be found not only in a new range of products and systems, but most of all in the dynamics of the relative cost structure of all possible inputs to production. In each new paradigm a particular input or set of inputs may be described as the 'key factor' in that paradigm characterized by falling relative costs and universal availability. The contemporary change of paradigm may be seen as a shift from a technology based primarily on cheap inputs of energy to one predominately based on cheap inputs of information derived from advances in microelectronics and telecommunications.'

Drawing on Kuhn's (1970) notion of a scientific paradigm,[35] and combining it with Schumpeter's (and Kondratieff's) notion of cycles in the economy, Perez and Dosi argue that a change in the techno-economic paradigm generates a new wave of innovations which in turn brings about economic development. Some of the conditions that encourage this to happen include the maturation of product life cycles; overcapacity and market saturation; the increased importance of diversified consumer demand; excessive dependence on non-renewable resources; and rising wages and declining productivity (Roobeek, 1987 in Buttel, 1995:28). Notably, these 'new' techno-economic paradigms are said to bring about a whole range of new products and processes which are designed to make use of developing technological, scientific and economic possibilities.

But whilst early notions of the 'new' techno-economic paradigm tended to focus almost exclusively on microelectronics, they have been extended to a cluster of technologies incorporating biotechnology, information technologies and new materials (Roobeek, 1995:63). Building on notions of 'industrial revolutions', technological development since the mid-1980s is seen to combine developments in microelectronics and information technology (IT) with those that have occurred in biotechnology.[36] Importantly, the 'new' paradigm is characterised by considerable

---

[34] Perez was the first to combine these ideas into a broader theory of economic development (Freeman, 1991:83).

[35] Kuhn's notion of a scientific paradigm has been hugely influential in both the histories of science and technology and more generally in social science. Broadly, his thesis is that science proceeds through periods of 'normal' science to moments of 'revolutionary' science. Based upon fundamental new insights that change the reference of empirical science, criticism of a current mode or 'paradigm' can accumulate to a point of crisis from which a new paradigm emerges.

[36] Castells (1996) applies the notion of a techno-economic paradigm to IT.

interaction between these clusters of technologies leading to a blurring of boundaries between science, technology and areas of knowledge (ibid.:67). Moreover, the encouragement of a complex interplay between technological, economic, and political forces provides the preconditions for new forms of social organisation (Freeman and Lundvall, 1988:74).[37] In a general sense, then, it is possible to link the emergence of a new techno-economic paradigm with the emergence of technoscience as both arise as means to accumulate capital.

For some writers technological innovation has a discontinuous nature. Following Schumpeter's 'creative gales of destruction' thesis, historical research on technological innovation has shown that there are identifiable patterns of ordered change as well as unpredictable discontinuities (Teece, 1988). This notion fits in with empirical evidence about biotechnology as it can be viewed as a 'discontinuous innovation' in that it has the potential to radically affect technological development in terms of both what and how it is produced (Dodgson, 1992:138). Discontinuous innovations are assumed to create technologies with marked performance and price advantages over existing technologies through competence enhancing - radical improvements on existing technologies - and competence destroying - fundamental differences from core technologies (Sahal, 1982 in ibid.). An articulation of this idea for agro-food systems is made by Goodman et al. (1987, 1991) who consider that biotechnology is leading to an increasing utilisation of non-agricultural raw materials and the creation of industrial substitutes for foods and fibres.[38] Goodman et al. (1987:2) argue that transformations are being brought about by two (discontinuous) processes: the first, *appropriationism*, involves 'the persistent undermining of discrete elements of the agricultural production process, their transformation into industrial activities, and

---

[37] It is interesting to speculate whether there have been paradigm shifts within biotechnology. According to Wilkins (1996), Kuhnian revolutions have never really happened because there has not been a decay in a prior paradigm. Strohman (1997a), however, argues that this is a narrow view. He points out that the discovery by Crick and Watson of the genetic code and DNA brought about new energy to an existing paradigm; in fact, all the usual features of a Kuhnian revolution - from a profound shift in the way the world is perceived to the rapid development of a new (bio)technology - appear to be present in the Crick-Watson discovery (ibid.:194).

[38] Whilst their thesis has been widely accepted as an interpretation of changes in agro-food systems, it has been widely criticised for its inability to take into account the empirical diversity of the agro-food system (Ward, 1994). Moreover, Goodman et al.'s work is viewed as technologically deterministic (see **footnote 20** in this chapter).

their re-incorporation into agriculture as inputs'; the second, *substitutionism,* is a similarly discontinuous but permanent process by which 'industrial activity accounts for a steadily rising proportion of value added, but the agricultural product, after first being reduced to an industrial input, increasingly suffers replacement by non-agricultural components'. Combined, these two processes contribute to the emergence of a bio-industrial complex which transforms traditional agro-food systems (Goodman and Wilkinson, 1991; Byé and Fonte, 1994; Goodman and Watts, 1994; Ahson, 1996a).

Economic perspectives on technological innovation assume that it is the accumulation of capital that is the central dynamic in modern capitalist societies (Dosi, 1988).[39] For Schumpeter, for instance, the dynamic behind modern capitalist societies is the profit made by innovators (Freeman, 1990:xvii). Capital, then, is the distinguishing feature of technological innovation. Capital is often referred to in terms of a physical product, such as investments in land and buildings, or finance or money (Healey and Ilbery, 1992:64). But as Marx points out, capital needs to be defined as a process rather than a thing. He writes:

> 'capital is not a thing, but rather a definite social production relation, belonging to a definite historical formation of society, which is manifested in a thing and lends this thing a specific social character....It is the means of production monopolized by a certain section of society, confronting living labour-power as products and working conditions rendered independent of this very labour-power, which are personified through this antithesis in capital. It is not merely the products of labourers turned into independent powers, products as rulers and buyers of their producers, but rather also the social forces and the...form of this labour, which confront the labourers as properties of their products. Here, then, we have a definite and, at first glance, very mystical, social form, of one of the factors in a historically produced social production process' (*Capital III,* ch. 48, in Bottomore, 1991:68).

The material manifestation of this process centres on a transformation from money into commodities back into things, with money as the material representation of capital, and with capitalism being the expansion of such value to produce 'surplus value' (Harvey, 1982:20). The whole movement of capital is considered in terms of 'circuits' (Bottomore, 1991:69), and it is this process of circulation from which surplus value (profit) is produced (Harvey, 1982:20-21). Capital, therefore, is the social relations that make the accumulation process possible (Carchedi, 1997:74).

[39] Economists sometimes call this 'appropriability'.

And it is these social relations which are important in technoscience (Tiles and Oberdiek, 1995). Of course, as Marx emphasises, there exist different or 'many' capitals. For example, knowledge as capital is considered to be the crucial factor of production in modern capitalist economies (Castells, 1996; Kenney, 1997; Morgan and Murdoch, 1998).[40] Importantly, the 'many capitals' that can be identified play different roles in accumulation strategies. The point to retain is that technological innovation both shapes capital and the processes of capital accumulation and is in turn shaped by them.

2.4.2 Sociological perspectives

It can be argued that the economic perspectives detailed above emerge from a narrow body of literature. By contrast, sociological studies of technology and technological innovation do not fit neatly into any one discipline or area of knowledge. For example, one of the major contributions of sociology to the study of technology emerged in the 1950s in the 'sociology of organisations' which explored the relationship between 'technology type' and 'organisation structure' (Coombs et al., 1992:4). Woodward (1965), for example, looks at the correlation between the type of technology used and the organisational structures adopted and concluded that certain core technologies predisposed a business organisation to favour certain structures. Similarly, during this period research was undertaken on the relationship between technology and the labour force in terms of the 'exploitative nature of technology' (Braverman, 1974), and the impact of the adoption of new technologies on work (Emery and Trist, 1960).

More important to the present discussion are the sociologies of science and technology (see, for example, Bloor, 1982; Callon, 1986a; Bijker et al., 1987, 1994; MacKenzie and Wajcman, 1996; Barnes, 1998). Commencing in the 1960s, sociological studies, or models of technology, began to emerge that examined the interaction between technological and societal development (Schot, 1992:185). These literatures are diverse and diffuse, but it is possible to identify three broad

[40] The importance of knowledge and knowledge production and their relation to capital as a characteristic of biotechnological innovation is discussed in **Chapter 7**.

approaches (Bijker et al., 1987; Bijker, 1995:6). The first, the 'social shaping' approach, views science and technology as being socially constructed, and thus aims to open up the 'black-box' of technology (and science). According to Grint and Woolgar (1997:19), one of the earliest versions of this approach is provided by Mumford. Mumford (1967, quoted in Mitchum, 1994:43) argues that all human technological achievements are:

> 'less for the purpose of increasing food supply or controlling nature than for utilizing his (sic.) own immense organic resources...to fulfil more adequately his (sic.) superorganic demands and aspirations.'

From this position, Mumford suggests that technology can be divided into two main types: polytechnics and monotechnics. The first of these is more orientated towards life and was said to be in harmony with humans as it acted in a democratic manner; the second is more focused on work and economic development (and thus dehumanising) (Mitchum, 1994:43). Mumford asserts that once humans recognise these two types of technology, they will redesign their lives around polytechnics which allow more social benefits to accrue (Grint and Woolgar, 1997:20).

A second version of the 'social shaping' approach is offered by Pinch and Bijker (1987). They show that the evolution of the bicycle, from an unstable device with a large peddle-driven front wheel to the much more stable machine with two equal wheels and a chain-linked rear wheel drive, was anything but a linear process. Rather than emerging from a specific idea which was taken through to production, its development was influenced by various interested socio-economic groups - such as female cyclists - at different times and places during the process. Thus like other technological artefacts, the bicycle is seen to be open to sociological analysis both in terms of its use and how it comes about (Bijker et al., 1987:4). More recently, Kline and Pinch (1996) have looked at how American society, particularly rural society, shaped the car. They argue that the users of technology act as agents for technological change. For example, particular social groups, especially those constructed around gender relationships, influenced the development of new gasline cars rather than cranking cars which were thought to be 'unfeminine' (ibid.:795).

The second perspective centres on socio-technical systems and the use of the 'system' metaphor to describe and explain technology.[41] Hughes (1983, 1987), in his studies of electrical, gas and lighting systems, explains the evolution of these industries in terms of 'seamless webs' which combine and fuse various 'social' and 'technological' factors and conditions. He stresses the importance of interlocking elements of physical artefacts, institutions, and their environment, and thereby integrates 'social' and 'technological' elements and issues into one approach (Bijker et al., 1987:4). Moreover, and central to his idea, Hughes proposes the notion of 'system builders'. For example, George Eastman and William Hall Walker not only developed the machinery to take photographs but also the machinery used in the production of film (Hughes, 1987:65). This allowed them to construct a system for amateur photography which they controlled through designing the necessary equipment for the whole process.

A different version of the 'systems' approach can be found in 'socio-technical' system theory which examines the links between the technical system of production and the social system of work (Grint and Woolgar, 1997:15). Broadly, writers using this approach propose that whilst technological innovation involves the interactions between 'social' and 'technological' elements, it is important to separate the individual parts for the purposes of analysis. As Trist writes, 'technical and social systems are independent of one another in the sense that the former follows the laws of natural sciences and the latter those of social/human sciences' (quoted in Van Eijnatten, 1991:11, in Grint and Woolgar, 1997:15). Leaving aside the dualism this view encourages, the socio-technical systems approach seeks to encourage the redesign of organisations in order to promote open systems of work (ibid.).

More importantly for this thesis is the third perspective centring on actor-network approaches. The network metaphor has been used by scientists (natural and social) to describe many forms of activity.[42] Whilst the study of networks

[41] It is important to be aware of the limitations of metaphors. As Richards notes (in Sennett, 1980:78), there is a danger that the metaphor creates a greater meaning than the sum of its parts.

[42] Networks have been used to describe a whole series of socio-economic activities. At least three main themes can be identified. First, it has been used to explain changes in the organisation of production which are said to fall into a network mode of organising (Cooke

(network analysis) is not especially new, a more compelling use of the network metaphor has been developed by actor-network theorists. An in-depth account of ANT is not attempted here (for which, see Murdoch, 1995), but a few details based on the work of Callon, Latour[43] and Law (often known as the 'sociology of translation') are useful. Three broad principles, or elements of this approach can be identified. The first centres on definitions of 'actors' and 'networks'. According to Murdoch (1994:19), defining actors is not especially clear in the work of actor-network theorists. Nevertheless, there is a broad consensus on the use of the term to describe any entity, human or non-human (Callon, 1986a). Therefore, ANT is a response to the tendency in sociology to bracket off the non-human, whether technological or natural (Lee and Brown, 1994:774), and is used to get away from privileging the status of humans (Latour, 1997a) or providing *a priori* definitions of actors or the role of non-humans in actions (Callon, 1997). Some actor-network theorists take a more prudent approach to definitions of actors. Hindess (1986:115) treats an actor as a 'locus of decision and action where the action is in some sense a consequence of the actor's decisions'. This means actors are not confined to individuals as they can refer to any entity constructed by actors; but they do not automatically cover the non-human.

Networks are used as unifying concepts which link different types of relations between actors, entities and artefacts (Murdoch, 1994:5). It follows that networks by this definition are not simply 'social' or 'technological' but are made up of heterogeneous materials that actors use to enrol/dominate others (ibid.:23). One of the defining features of ANT is that the 'social' and 'technological' are not set up as opposites (Latour, 1993; Prout, 1996; Murdoch, 1997). Specifically defined or 'hard' categories, such as 'social' and 'technological', are seen by actor-network theorists to be too rigid; instead, 'networks' are seen to dissolve all these categories which then blur into each other:

---

and Morgan, 1993; Osborn and Hagedoorn, 1997). Second, it is employed to describe the behaviour of individuals, especially in relation to making connections in socio-economic activity (Nitin, 1992). Finally, networks have been proposed as a model for industrial policy, and especially in the role they might play in creating a strong innovative economy (Fairtlough, 1996).

[43] Latour's work on networks is ambiguous. Quite apart from the fact that he recently seems to have moved away from using the idea of 'networks' (Latour, 1997b), in the corpus of his work it seems to be a bit of a side issue (see, for instance, Latour, 1993; 1996).

> 'the technical is always, already, contained within the social. And...the social is always, already, located within the technical. And, perhaps,...the terms 'technical' and 'social' no longer serve so very well. Or all too well. For concealing the possibility that they are not helpful' (Law and Mol, 1995, in Hinchliffe, 1996:664).

Accepting this position, Latour argues (1997a:2) modern societies cannot be described:

> 'without recognizing them as having a fibrous, thread-like, wiry, stringy, ropy, capillary character that is never captured by the notions of levels, layers, territories, spheres, categories, structure, systems.'

In dissolving categories such as the 'micro' and the 'macro', spatial metaphors can be seen to be reshuffled by actor-network theorists (ibid.:4). In fact, the network is considered by some writers to involve an alternative topological system; that is, it is a form - or perhaps family of forms - of spatiality (Law, 1997a, 1997b; Cox, 1998). Critically, as Latour (1997a) points out, the network is a reaction to broad and global concepts such as institutions, states, and nations; the network is seen to emphasise more realistic and smaller sets of associations and relationships. Networks of relations can be seen to operate over various spatial scales (Murdoch and Marsden, 1995). Importantly, networks are uneven in area forms as the boundaries around them tend to be porous (Cox, 1998:2-3). Actors, on the other hand, can be viewed as network effects as they take the attributes of the entities which they include (Law, 1997b). Alternatively, 'actors' and 'networks' can be seen to be two faces of the same phenomenon (Latour, 1997a). Taken together, Latour (1997a:2) argues that 'there is nothing but networks'.

A second element of ANT centres on how some actors are able to get other actors to comply with their position, and how this compliance is maintained. Based on the frequently cited case of a scientific and economic controversy over the decline in population of scallops in St. Brieuc Bay (France), Callon (1986a:203) describes the four stages of this process. Here three scientists present new knowledge acquired from a trip to Japan on how best to solve the depleting stocks of scallops and construct a network of actors to achieve this. The first stage, *problematisation*, occurs when an actor makes itself indispensable to others. The second stage, *interessement*, involves the actor's attempt to lock others into place by coming between them and their alternatives. The third stage, *enrollement*, entails the construction of a network of passive agents which forms part of the actor (hence term actor-network). The final stage of the process of

translation takes place when the actor borrows the force of the passive agents that it has 'enroled' by turning itself into their spokesperson and talking on their behalf (Law, 1986a:15-16). Clearly, then, as Thrift (1996:24) points out, the establishment and maintenance of networks is the central aspect of ANT.

A third feature of ANT is the centrality of power. According to Latour (1986:264-265), the problem with power can be summarised in the following (much quoted) paradox:

> 'when you simply *have* power - *in potentia* - nothing happens and you are powerless; when you *exert* power - *in actu* - others are performing the action and not you. To take an example, Amin Gemayel in his palace officially has power over the Lebanon, but since very few people act when he orders things, he is powerless in practice. Power is not something you may possess and hoard. Either you have it in practice and *you* do not have it - others have - or you simply have it in theory and you do not have it' (italics in the original quote).

Power, therefore, is seen as an outcome of the strength of the associations between actors. That is, it is not something that is possessed but rather is a consequence. Thus to go back to the construction of networks, the stronger they are the more powerful the translating actor (Murdoch, 1995:748). Put differently, power is a 'composition' made up of actors but attributed to just one of them (Murdoch and Marsden, 1995:372). Critically for Callon (1986a:224):

> 'Understanding what sociologists generally call power relationships means describing the way in which actors are defined, associated and simultaneously obliged to remain faithful to their alliances. The repertoire of translation is not only designed to give a symmetrical and tolerant description of a complex process which constantly mixes together a variety of social and natural entities. It also permits an explanation of how a few obtain the right to express and to represent the many silent actors of the social and the natural worlds they have mobilized.'

ANT offers a non-hierarchical 'modest sociology' for the study of particular phenomena (Law, 1994). It can be used to see how things are 'done in practice' (Thrift, 1996:25), especially with regards to the ordering and stabilisation of technoscience (Hinchliffe, 1996), and the assumptions and values that accompany socio-economic activity (Barnes, 1998). Generally, ANT points to multiple realities, many ontological interactions and intersections, and a ceaseless making, linking and clashing that are connected to social life (Law, 1997b). But above all, ANT points to thinking about particular phenomena such as technological innovation in terms of networks.

2.5 An analytical framework for (bio)technological innovation: 'after' and 'beyond' actor-network theory

What general points can be distilled from the perspectives described above? And how can they be used to formulate a conceptual framework for analysing innovation in (agro-food) biotechnology? In general terms, emerging from the economic perspectives, is a restatement of the importance of technoscience for modern capitalist societies and the central role it plays in the generation of capital. Moreover, there is some understanding of its discontinuous nature as its 'creative destruction' tendency acts as both a source of instability and growth in capitalism. Finally, there is a strong sense that (bio)technological innovation needs to be looked at beyond the 'technological'. From the sociological approaches there is a recognition that 'social' factors play a central role in technological innovation. Furthermore, these perspectives insist that inquiry must look within the 'black box' of technology and see how it comes about.[44]

But in practice the dichotomy posed above between economic and sociological perspectives is too sharp. The differences set up in this chapter between economics and sociology are somewhat artificial given the long history of interaction between economic theory and social theory. For example, it is worth pointing out that social theory as a theory of social action has been profoundly shaped by the analytical problems of economic analysis (Turner, 1996:2). The preceding discussion even suggests connections between these economic and sociological perspectives on technological innovation. Indeed according to Callon (1992:72), these perspectives are complementary as technoscientific innovation emerges from the interaction of various actors (human and non-human) which together produce (techno-economic) networks (see also Mackenzie, 1992:39; Richards and Ruivenkamp, 1996). Thus an analytical framework which rests at the juncture of economic and sociological perspectives seems to be the most appropriate way for investigating (bio)technological innovation in modern capitalist societies. The use of the network by ANT is seen to be especially helpful in achieving this task. As Thrift (1996:24; see also Murdoch, 1995:747) writes:

[44] As Latour (1987:15) writes, 'few people have penetrated from the outside the inner workings of science and technology, and then got out of it to explain to the outsider how it all works.'

> 'It is often written that actor-network theory is an attempt to combine the insight of economics, that it is *things* that draw actors in relationships, with insight of sociology, that actors come to define themselves, and others, through *interactions*' (italics in the original quote).

But ANT has been quite heavily criticised on a number of grounds. Leaving aside methodological concerns (for which, see **Section 4.4**), there are a number of theoretical limitations. One of the most controversial features of ANT is the lack of a distinction made between human and non-human actors. According to Collins and Yearley (1992), quite apart from the moral and ethical implications of this difference (are there, for instance, differences between children and scallops? [Lee, 1994:281]), this notion concedes too much to realist and technological determinist accounts. Additionally, Lee and Brown (1994) argue that the categories of 'human' and 'non-human' are solely the result of human activity or human social construction. Moreover, they suggest that with ANT, a 'Nietzschean worldview and discourse of liberal democracy' are taken to their extreme leading to yet another ahistorical grand narrative on who has the right to speak. Put differently, because of the tolerance of ANT, one is left with presenting an actor which is anonymous, ill-defined and an indiscernible entity; that is, actors and networks appear to be everything (Callon, 1997). A further point, argued by feminist writers of science and technology, is that the claims of ANT of being a non-hierarchical approach can never be sustained because they tend to explore the strategies of the powerful, rather than attending to the difficulties of women, people of colour, or others who do not conform to the standard conventions (Star, 1991). Also, according to Lagendijk (1998:14), ANT's explanatory framework, largely based on the notion of the extension of networks, lacks any notion of agency. Here, actors are presented in terms of their development of associations and processes of translation, and primarily driven by the search for power - a view which even actor network theorists find cannot be totally justified (ibid.). Contrastingly, Kleinman (1998:288) argues that ANT focuses too much on agency and neglects or underplays the constraints placed on agents in their efforts to act. Finally, although actor-network theorists reject the notion that technology (and science) has an essence (Hinchliffe, 1996), they still rely upon definitive accounts of the actual properties that make up the actor-networks (Grint and Woolgar, 1997:30-1). In this respect, ANT has a technological determinist tenor.

Not surprisingly, actor network theorists have responded to these criticisms in a number of ways. Law (1997b), for instance, argues that ANT is dealing more with a diverse set of practices rather than specific principles[45] and, therefore, whilst many aspects of ANT can be criticised, the need for many narratives, modest sociologies and ontological realities still holds. He also argues that the 'oxymoronic' nature of ANT - it involves a tension between a centred actor on the one hand and a decentred network on the other - allows a elision between what is frequently called by Anglophones 'agency' and 'structure' (Law, 1997a). For Callon (1997), despite the indeterminacy of the 'actor', and the consequent limits to its analytical use, ANT nevertheless provides a clear sense of the possible configurations of action. Cussins (1998) argues in a different vein, that whilst ANT may appear as dehumanising this view is based on the assumption that there is something wrong with being treated as an object. Finally, Latour (1997b), in an 'after ANT' sense, proposes that the problem with ANT are the words 'actor', 'network', 'theory', and the hyphen, and therefore as a term should be abandoned.[46] He suggests, however, that what will come out of this process of abandonment will be new and more interesting ways of understanding the world (ibid.:4).

Criticisms of ANT, and responses to them, notwithstanding, one question remains unanswered: Can ANT be specifically used to explain and understand biotechnological innovation? It is clear from the account above that actor-network perspectives hardly constitute a coherent body of work. And not surprisingly it is difficult to be precise about what an 'actor network study' would entail. For instance, if the approach from Callon (1986a, 1986b) is taken, the study would need to concentrate on the process of 'translation' and the ways actors constructed networks. By contrast, an approach adapted form the work of Law (1994) might be more inclined to examine the particular configuration of the material and non-material aspects which combine in particular processes. Alternatively, a study of 'actor-spaces' drawn from Murdoch and Marsden (1995) might concentrate on examining the ways in which actors are linked together within particular sets of (power) relations. And finally, exploring the

[45] Law (1997a) notes that 'actor-network' was translated from the French 'acteur reseau'.
[46] For Latour (1997b:1) the problem with using 'network' is the danger of a metaphor which is over 20 years old and which is generally employed differently by other commentators. The problem with 'actor' is that its connection to the network with a hyphen invokes the structure/agency debate. ANT does not overcome this debate: actors and networks do not correspond to agency and structure but are two faces of the same phenomenon (ibid.:2). Lastly, it is not clear what ANT is a theory 'of'. Broadly, it is not a theory of the social but one of 'space and fluids circulating in a non-modern situation' (ibid.:3).

geographies of technoscience may require a look at materials and texts which connect the 'social' and the 'technological' (Hinchliffe, 1996). Therefore, there are many approaches to what an 'actor-network' study may involve. Added to this, there are considerable methodological uncertainties around how to undertake such a study given the lack of methodological insight from actor-network theorists (see **Section 4.4.2**). This study, therefore, does not seek to apply ANT to the study of biotechnological innovation. Instead a particular aspect of ANT emphasised by actor-networks theorists - namely the network - is used. Taking some of the arguments discussed above to their logical conclusion, it quickly becomes evident that biotechnological innovation needs to be conceptualised in terms of a network. Broadly, biotechnological innovation can be conceived of in terms of a network which links 'social' and 'technological' elements together and which is driven by the need to accumulate capital. In this case, then, the approach developing here uses the 'network' as an analytical tool to identify and analyse how particular actors, activities and conditions come together in biotechnology. Critically, the 'network' is used to liberate this study from excessively areal approaches in the study of innovation in agro-food biotechnology. What is more, it is used to provide a conception of biotechnological innovation which goes beyond the interaction and strategies of particular firms, through highlighting the multi-dimensional character of innovation. The analytical framework developed in this chapter can be used to investigate the causes and effects of biotechnological innovation.

2.6 Summary

This chapter outlines a new approach to the study of innovation in (agro-food) biotechnology. Instead of following well-established but disciplinary specific theoretical perspectives, it proposes that by combining approaches from economics and sociology, a fuller more realistic picture of biotechnological innovation can be obtained. Using the notion of the 'network' from ANT perspectives, biotechnological innovation is conceptualised in terms of a network which links 'social' and 'technological' factors together. This spatial form transcends dominant categories and concepts such as firms, institutions, and states as it emphasises smaller sets of associations and relationships in biotechnological innovation. In addition, the network can be employed to link and examine both the input and output aspects of

biotechnological innovation. Behind the formation of the network it is assumed that the accumulation of capital is the central dynamic in modern capitalist societies. But the network of biotechnological innovation is also sensitive to, and reflects, key 'existential' factors that characterise technoscience, such as relations between 'science' and 'technology'. Having presented a framework for the analysis of innovation in (agro-food) biotechnology, it is argued that the model presented above sets out a general scheme for technological innovation. Of course, it remains to be seen how this conceptual framework can be translated into a methodology, the aim of **Chapter 4**. In the next chapter, the highly abstract version of how (bio)technological innovation takes place as presented here is contextualised by a more in-depth introduction to agro-food biotechnology. This contextualisation will assist the conduct of subsequent empirical inquiry.

3

WHAT IS (AGRO-FOOD) BIOTECHNOLOGY?

3.1 Introduction

This chapter provides an overview of some of the key concepts and elements of (agro-food) biotechnology. Quite apart from the growing consensus on the importance of biotechnology for many aspects of our lives, as an activity it is still unfamiliar, not least because there are many definitions of biotechnology.[1] At the most general level, it is seen to involve 'the application of biological organisms, systems, and processes based on scientific and engineering principles, to the production of goods and services' (OECD, 1992:29).[2] More specifically, it exhibits three main characteristics. First, and in an obvious sense, biotechnology is biological in nature. This does not necessarily mean that the organisms employed are always living (enzymes, for instance, are 'dead'), but that unlike chemical compounds, they may have been living at some point (Wildavsky, 1991; Bud, 1993). Second, biotechnology is neither a separate nor distinct science or technology; rather, as the definition suggests, it involves a range of disciplines or areas of knowledge - genetics, molecular biology, biochemistry, embryology and cell biology, for instance - used in a range of production processes, combined with some more applied areas of technology such as chemical engineering, information technology, robotics and material sciences (OECD, 1992:29; Roobeek, 1995). Critically, biotechnology is a general term which refers to a wide range of technologies and techniques and which displays multi-/inter-disciplinary characteristics (Moser, 1994; Durant, 1996).[3] Third, biotechnology is frequently used

---

[1] One senior professor in biochemistry interviewed during my fieldwork knew of somebody who had identified over 128 different definitions of biotechnology (see **Section 5.3**).

[2] Another widely used definition of biotechnology proposed by the European Federation of Biotechnology (EFB) is 'the integration of natural sciences and engineering sciences in order to achieve the application of organisms, cells, parts thereof and molecular analogues for products and services' (EFB, 1995).

[3] It is perhaps useful to make some form of distinction between 'multi-disciplinary' and 'inter-disciplinary'. Broadly, I consider multi-disciplinary work to entail the working together or interaction of different areas of knowledge and disciplines. By contrast, I treat inter-disciplinary as more suggestive of a blurring of boundaries and the formation of, perhaps, a more holistic integrated discipline. These points notwithstanding, it is important

to cover traditional techniques such as the exploitation of living material in fermentation, as well as more recent advances such as rDNA technology (the production and transfer of genes between organisms) (Fransman et al., 1995; Price, 1995; Macer, 1996).

And yet underlying these characteristics, there are significant differences in opinion over the specificity of definitions of biotechnology leading to the issue of whether it is a useful term at all (Buckwell and Moxey, 1990; Bud, 1993:212; Jones, 1993). For example, some writers suggest it covers any activity that uses 'living' organisms (Macer, 1996). Alternatively, biotechnology can be used to refer to the more recent techniques, such as genetic engineering, which allow organisms to be employed precisely (Grace, 1997). It follows that it is necessary for this study to consider the question 'What is (agro-food) biotechnology?' This chapter has two main sections. In **Section 3.2,** a brief historical outline of the development of biotechnology is given. Especially relevant are the links between 'traditional' and 'modern' forms of biotechnology. **Section 3.3** deals more specifically with biotechnology as used in agro-food systems, and an overview of the 'potential' and 'actual' aspects of biotechnology is provided. The discussion in this chapter is crudely interested in biotechnology in 'technological' and 'scientific' terms rather than in their socio-economic effects. Moreover, as noted in **Chapter 1**, the contribution here does not seek to offer an extensive and detailed overview of *all* areas of biotechnology, but directs its analysis towards agro-food systems.

3.2 A brief history of biotechnology

There is considerable consensus that biotechnology is a key element of technoscience for modern capitalist societies. Generally, the history of biotechnology can be divided up into five main periods (see **table 3.1**; cf. NEDC, 1991:vii; *Le Soir*, 1996; Grace, 1997:28-9). Biotechnology applied in the production of

---

to recognise that these two words frequently have been used interchangeably. As a final point, to say that people from different disciplines are working together is one thing; to say that this is an example of a more 'holistic' approach is altogether something else. Added to this, the 'blurring' of boundaries between disciplines or areas of knowledge could be construed as not being especially new. For example, in the evolutionary theory of Darwin, biology was combined with geology.

alcoholic beverages, cheese and bread has been practised according to some reports for over 8000 years (Andersen, 1991; Madden, 1995; FDF, 1996b). During this period, biotechnology had little scientific basis; even the discovery of micro-organisms as the smallest living creatures by van Leeuwenhoek in 1650 did not lead to any real understanding of their significance (Knorr, 1987). This understanding began to change with Louis Pasteur's proof that living micro-organisms were the active agent of fermentation. It led from a descriptive biology to an understanding of the biological process. In the third period, the anti-biotic era, matters changed radically. A bioindustry began to emerge as different disciplines, such as biochemistry and chemical engineering, enhanced the scope and efficiency of the fermentation industries. Importantly, during this period conventional chemical and food processing technologies, such as the production of penicillin on a large scale, began to have a considerable impact on human and animal heath care These developments continued during the post-antibiotic era which were marked by developments in metabolic engineering. In the main, micro-organisms began to be used in the production of enzymes and metabolites, and included the large scale enzymatic conversion of starch to high fructose corn syrup (HFCS). The fifth and current era of modern biotechnology can be traced back to the mid-1970s with the application of rDNA technology and more 'controlled' sciences. On the face of it, modern biotechnology is said to combine these 'traditional' and 'modern' techniques and technologies. For example, to make use of the results of rDNA technology, the more traditional technologies such as tissue culture, fermentation and enzyme technology have to be applied (Jones, 1993:26; Fransman et al., 1995:2).

Table 3.1: History of biotechnology

Pre-Pasteur Era (before 1865)
- Alcoholic beverages (beer, wines)
- Dairy products (cheese, yoghurt)
- Other fermented food, yeast vinegar

Pasteur Era (1865-1940)
- Ethanol, butanol, acetone glycerol
- Organic acids (citric acid)
- Aerobic sewage treatment

Antibiotic Era (1940-60)
- Penicillin: submerged fermentation technology
- Large variety of antibiotics
- Animal cell culture technology; virus vaccines
- Microbial steroid transformation

Post-Antibiotic Era (1960-75)
- Amino acids
- Single-cell protein (SCP)
- Enzymes (detergents)
- Immobilised enzymes and cell technology (isomerase)
- Anaerobic wastewater treatment (biogas)
- Bacterial polysaccharides (xanthuim gum)

Era of New (Modern) Biotechnology (1975-present)
- Hybridoma technology: monoclonal antibodies (1975), monoclonal diagnostic tests (1980)
- Genetic engineering (1974): animal diarrhoea vaccines (1982), human insulin (1982), insect resistant plants (1985), animal and human growth hormone (1986), transgenic animals (1988), human genome mapping (1989), DNA chips (1996), animal cloning (1997), human cloning (199?)

Sources: Knorr (1987:96), *Economist* (1988, 1995), OECD (1989, 1992), NEDC (1991), Arthur Andersen (1994, 1997), Grace (1997)

The combination of 'traditional' and 'modern' techniques for biotechnology is unsurprising as a number of key accounts of the history of biotechnology have highlighted these connections (see, for instance, Kloppenburg, 1988). But according to Bud (1993), despite these 'ancient' links, it would be wrong to equate them fully with 'biotechnology' as we know it today; instead, the bridge between biotechnology's ancient lineage and our current uses can be found in zymotechnology.[4] Coming from the Greek root *zyme*, meaning leavening, zymotechnology refers to all types of industrial fermentation. Generally, it is seen to be an ensemble of disciplines and skills which have descended from German chemistry of the 17th century (it first seems to have been coined by the Prussian court physician Stahl in his book *Zymotechnicnia Fundamentalis*, published in 1697) (ibid.:8). From the 19th century, the growing importance of the distinction between natural and chemical products as reflected in the synthesis of urea, pointed to how

[4] A full history of zymotechnology is beyond the scope of this thesis. See Bud (1993, Chapters 1-2) for a more detailed description and discussion of the history of zymotechnology and its connection to biotechnology.

biological processes could be exploited. During its development, zymotechnology began to transcend its traditional applied chemistry basis as it became related to a range of techniques associated with fermentation, such as chemical engineering. Together, these techniques created an 'interface' between science and industry. Compared to organic chemistry, however, up until the mid-19th century, zymotechnology was still on the periphery, and it was not until Louis Pasteur, with his emphasis on microscopy, did fermentation become recognised as a key area of research (ibid.:14).[5]

The term 'biotechnology' emerged in Hungary in the early part of this century (Madden, 1995:1). Karl Ereky, in an attempt to transform his country into a 'southern Denmark', wrote a number of papers aimed at peasants including *Biotechnologie der Fleisch-, Fett- und Milcherzeugung in landwirtschaftlichen Großbetriebe*[6] (Bud, 1993:32). In this paper, using the example of pig breeding, he outlined his vision for agriculture: the difference between industrial and peasant pig rearing lay in the underlying scientific approach, namely biotechnology. Interestingly, for the history of biotechnology, Ereky believed that the chemical industry would come to the aid of the peasant by upgrading biologically raw materials (ibid.:34-5).

Herein, it would seem lies the genus of biotechnology. But what makes modern biotechnology different is linked to two key discoveries (Davis, 1991; Taverne, 1991). The first involved the discovery of the structure of deoxyribonucleic acid (DNA) by Crick and Watson in 1953 using crystallographic data and biochemical reasoning (Cantley, 1995:509).[7] Genetic information in the form of genes can be found in every living cell, and are required for the synthesis of

[5] The history of zymotechnology was closely related to agriculture. As Bud (1993:15-17) notes, when the production and processing of agricultural produce became increasingly competitive between countries, intensive farming was encouraged particularly in the Netherlands, Denmark and the German states. In the case of Denmark, in order to move 'up-market', the Danes turned to intensive livestock production and milk technology. Similarly, brewing was also of critical importance for zymotechnology; for instance, the value of the brewing industry in Germany was the same as their steel industry in the 19th century. In 1883, the Danish scientist Emil Christian Hansen made an important breakthrough for the brewing industry when he found that bacterial infection could ruin a brewing process (ibid.:17-21).

[6] Biotechnology of meat, fat and milk production in large-scale agricultural industry.

[7] See Watson's (1968) personal account of the discovery of DNA for an interesting history of this event.

thousands of proteins which enable the cell and the whole organism to perform all its biological functions (La Roche, 1992:59: Grace, 1997:12-30). Genes are made up of DNA, which are formed into two long strands intertwined in a spiral - the 'double helix'. Each of these strands is made up of four bases (adenine, thymine, cytosine and guanine) and are put together in different sequences to create a code, each of which contains particular instructions for reproduction. Whilst historically genetic modification[8] can be traced back to Mendel, the Moravian monk who laid the foundations of modern genetics by developing the idea of particulate inheritance, Mendelian 'classical genetics' changed radically with Crick and Watson's discovery (Durant, 1996; Jones, 1996). Their discovery provides answers to how DNA is able to store and pass on a practically infinite number of bits of hereditary information (Grace, 1997:15). Following the double helix discovery, the second major discovery, came in 1974 when Boyer and Cohen developed a recombinant technique (Cantley, 1995:510). Essentially, this entails the use of restriction enzymes with bacterial plasmids, and allows a section of DNA to be cut from the plasmid of an *E. coli* bacterium and transferred into the DNA of another organism (ibid.). Since then, techniques of molecular biology have been developed which permit the isolation or biochemical synthesis of individual genes from a higher organism and their incorporation into micro-organisms such as bacteria (La Roche, 1992:60).

Together, the discovery of the structure of DNA and rDNA techniques and technology form the basis of what is commonly called genetic modification. Genetic modification is a broad term but the basic principle behind it is that DNA can be transferred from a cell of one species and made to express itself in another cell. The key components of genetic modification are: identification and isolation of suitable genes to transfer; delivery systems to introduce the desired genes into the recipient cells; and expression of the new genetic information in the recipient cells (Persley

[8] Initially called genetic engineering, later renamed as genetic manipulation (Levidow et al., 1997). According to some commentators this shift denotes only a 'modest shift in nature' (Levidow, 1996:62), and these terms have often been used interchangeably. It is possible to identify a technoscientific difference; for example, genetic modification can refer to an enzyme with a copy of a gene from which a multicopy is made; genetic engineering can involve changing the gene itself. But the difference between these three terms could be rooted in semantics; for instance, modification may be considered more 'neutral' and therefore more appropriate in certain contexts, than manipulation. Of course, semantic differences are not necessarily neutral as 'modification' can also be thought of as unacceptable in certain circumstances.

and Peacock, 1993:5). Importantly, as noted in **Section 3.1**, biotechnology, and genetic modification specifically, are generally considered not to be a separate or distinct science or technology; rather they involve the interaction and fusion of a range of disciplines and areas of knowledge. The principal technologies that currently make up biotechnology include gene amplification, DNA sequencing, DNA synthesis, diagnostics kits (for clinical use and research), DNA probes, protein synthesis, protein sequencing, monoclonal antibodies, cell/tissue culture and engineering, purification/separation, electrophoresis, transgenic plants and animals, gene therapy, gene antisense technology, biotransformation, and enzyme engineering (Europabio, 1997:21).[9]

What this description suggests is that modern biotechnology (hereafter biotechnology) in the form of genetic modification is a completely new technology: it opens the door to a detailed understanding of the form and organisation of genetic structures in higher organisms, of the control of gene expression, and of the processes of cellular differentiation (Sinsheimer, 1983:64). Unsurprisingly, biotechnology is often described as 'revolutionary'[10] (from among many examples, see Davis, 1991; Webster, 1991; Fransman et al., 1995; Durant, 1996; Grace, 1997; King, 1997). Take for instance the possible economic impact of biotechnology. Given the gaps between what is technologically feasible and what is actually achieved, measuring the economic impact of biotechnology is problematic (OECD, 1989:19, 1992:30). Nevertheless, some crude forecasts for the market size of biotechnology have been made (see **table 3.2**). Notwithstanding the huge variations in the figures in the table which point to the difficulty in undertaking market forecasts, one point is clear: biotechnology has an important role to play in industry.[11]

---

[9] For an easy to understand description of some of these techniques see Russo and Cove (1995).

[10] It is worth pointing out that the words 'revolutionary' and 'new' have been used so often to describe things which hardly merit mention anymore.

[11] Given these estimated figures, it is unsurprising that biotechnology has been the focus of considerable attention in the area of industrial policy. In the UK, for instance, the Department of Trade and Industry (DTI) set up the Biotechnology Means Business (BMB) initiative to increase awareness amongst UK industry of the opportunities biotechnology presents (DTI, 1996a). Similarly, the CEC has set up a range of programmes to encourage the development, production and application of biotechnology in industry (CEC, 1996b). **Section 6.3.3** provides a more detailed account of these programmes.

Table 3.2: Forecast on size of worldwide market for biotechnology derived products (in millions of dollars)

	Year	Total	Pharmaceuticals and health care	Chemicals	Agriculture and food processing	Energy
Business	1982	59	26			
Communications Co.	1990	13 000	12 600	270	430	
Robert S. First Co.	1985		1 400	250		
	2000		43 000	8 200		
Genex Corporation	1990	10 000				
International Resources Development	1985	520				
	1990	3 000				
International Planning Information (UK)	1990	4 500				
	2000	9 000				
Arthur D Little	1990				2-4 000	
	2000		23 000			
Policy Research Corp.	2000		5-10 000		50-100 000	
Predicasts, Inc.	1985		1 120		6 200	
	1995		18 600		101 000	
T.A Sheets and Company	1990	27 000	2 900	5 100		9 400
	2000	64 000	9 100	10 600	21 300	16 400
Strategic, Inc.	1990		5 000		4 500	
	2000				9 500	
US Congress, Office of Technology Assessment/ Genex Corporation	1990					
	2000	14 600				

Source: High Technology Industries, Profits and Outlook: Biotechnology, US Department of Commerce, International Trade Administration/Genex Corporation, Washington DC 1984 (in OECD, 1989:20)

Biotechnology is also said to involve a blurring of boundaries between various areas of knowledge and disciplines.[12] In the production of enzymes, for instance, biochemical engineers work closely with organic chemists; in turn, organic chemists work closely with production engineers. Similarly, it could be argued the 'revolution' in biotechnology might be associated with the ascendancy of the biological sciences (Sinsheimer, 1983; Mayr, 1988; Levidow, 1996). Over the course of the last century, technoscience has been dominated by (nuclear) physics, both in terms of money and prestige with 'big' projects such as the *Centre European de Recherche Nuclear* (CERN) in Switzerland being a major feature of technoscience. But with its own 'big' project, the HGP (Balmer, 1996), biotechnology is said to offer the possibility of finding solutions to certain 'societal' problems (Geschwindt, 1997; Cantor, 1998).[13] For example, the recent discovery of a single gene that protects

[12] It must be said that this 'blurring of boundaries' is a strong theme in much of the 'post-modern' literature on technoscience. For some recent examples, see Gilbert (1995), Aronowitz et al. (1996) and Luke (1997).

[13] On May 21 1996, British Biotech became one of the four most highly valued biotechnology companies in the world on the announcement of phase II clinical trial results for its anticancer drug, Marimastat. The company's share price temporarily leapt over 25 percent to £38.25 giving the company a valuation of £1.9 billion putting it nearly in among the top 100 UK publicly traded companies (*Nature biotechnology*, 1996). Interestingly, it is not

against cancerous chemicals is opening up the potential use of rDNA techniques and technology to prevent certain cancers (*Guardian*, 1998b). Of course, at the risk of stating the obvious, biotechnology's 'revolutionary' potential is clearly a matter of contention. Nevertheless, the scale and scope of the impact of biotechnology on society could be considerable (Hodgson, 1997a). In few areas is this impact likely to be more profound than in agro-food systems.

3.3 Biotechnology and agro-food systems

Up to this point, biotechnology has been examined in a general rather than a specific sense. At this stage it is critical to make more explicit particular features and linkages of biotechnology to agro-food systems. The scope of biotechnology for industry is enormous; some of the industrial sectors in which it is employed include chemicals, pharmaceuticals, energy, food, agriculture, and service industries (Marks, 1993:103; Aldridge, 1997). The application of biotechnology to agro-food systems is perhaps the most important. In Europe, for instance, it is estimated to account for 58 percent of the total value of the biotechnology sector (Europabio, 1997:10); recent estimates predict that within 10 years, 70 percent of biotechnology growth will be in the agro-food sector (Burke and Thomas, 1997).[14] From the description in **Section 3.1**, it is clear that biotechnology is closely linked to the history of food and drink provision: from the ancient production of bread and cheese to the more recent production of novel foods.[15] But the impact of modern

---

guaranteed that this product will enter the market and if it does it will be no sooner than 1999. More recently, however, British Biotech announced that it was within months of launching its first product, Zacutex for acute pancreatitis (*Financial Times*, 1997a). Interestingly, shares fell slightly because it this was not its anti-cancer drug. That said, over the last few months British Biotech has been accused of fixing trial results for one of its major products and as a result its share price has dropped dramatically (*Guardian*, 1998c). The recent turmoil with British Biotech's shares is not unusual as Celltech's shares plummeted on the announcement that its septic shock treatment - a reaction to blood poisoning - was being dropped after disappointing trial results (*Financial Times*, 1997b). Taken together, it is clear that the biotechnology industry is not always bullish. **Chapter 8** explores this issue further.

[14] As I have argued elsewhere (Ahson, 1998), there is a tendency to concentrate on developments in human health care. Whilst I do not analyse the reasons for this, I think this broadly reflects the fact that people are more likely to accept the use of biotechnology in this sector than in agro-food systems (see Zechendorf, 1994; CEC, 1997a).

[15] It is interesting to note that this link between 'traditional' and 'modern' has been emphasised in much of the literature used to inform consumers about modern

biotechnology could go well-beyond the types of food products produced. According to many writers (see, for instance, Goodman et al., 1987; Goodman and Redclift, 1991; NABC, 1991; Hayenga, 1993; Madden, 1995; Mannion, 1995, 1997; Ahson, 1996a; King, 1997; Margolis and Duyk, 1998), biotechnology is likely to affect the main structures, agents and processes in agro-food systems. Given the already considerable attention focusing on this issue, a full treatment of the subject is not attempted in this chapter. Instead, here the attention is focused upon the areas where rDNA technology and genetic modification will affect agro-food systems.[16]

There are various ways in which agro-food biotechnology can be categorised. The most common approach involves outlining food and drink products produced using biotechnology, such as cheese, bread, vinegar, fruits and vegetable products, and the by-products of fermentation such as enzymes, flavours and additives (EFB, 1994:1). Virtually absent from such descriptions, however, is a recognition that the impact of biotechnology on agro-food systems is not limited to *products*. The impact of biotechnology on *processes* will be just as substantial, and a more helpful means of categorisation adopts a *systems* approach which roughly follows the food chain. It covers the main areas of agro-food biotechnology - raw materials; processing aids; food material; waste material; and the environment (Knorr, 1987:97).[17]

Three riders need to be added to this approach. First, it is important to recognise that these categories are roughly divided and there is considerable overlap between them. Second, given the distinction between what may be feasible in technological terms and what is actually achieved (particularly in relation to the commerciability of biotechnology), the categories include both *actual* and *potential* developments in agro-food biotechnology. Third, the contribution here does not offer an extensive review of all potential and actual developments in agro-food biotechnology (for which, see OECD, 1992). Instead, the aim is to provide an

---

biotechnology (see, for example, FDF, 1996a; 1996b, 1996c; 1998). **Section 5.3.1** provides an in-depth analysis of the relationship between 'traditional' and 'modern' biotechnology.

[16] In the main, I will use 'rDNA technology' for the remaining part of this thesis to refer to modern developments in biotechnology.

[17] This organisation of agro-food biotechnology is also used for developing the research techniques (**Chapter 4**) and presenting and analysing results (**Chapter 5**).

overview highlighting some key aspects for the study of biotechnological innovation.

3.3.1 Raw material

The area of raw material can be roughly divided into plant and animal parts. Plant biotechnology has progressed rapidly since the production of the first transgenic plants in 1983 (Flavell, 1995; Mazur, 1995; Winstanley, 1995; Vasil, 1996). Dozens of transgenic plants have been field tested successfully, and it is estimated that the commercial value of such wheat alone is US$60 billion (Beck and Ulrich, 1993; J. Smith, 1994a:683). Some of the traits inserted into these crops include the following: genes designed to protect crops against pests; genes that enhance the resistance of crops to particular physical stresses such as freezing or saline soils; and genes designed to alter the character or quality of foods (Kareiva and Stark, 1994:52-53). In technological terms, advances in crop biotechnology have been brought about by two significant breakthroughs: the development of efficient systems for the regeneration of plants from cultured tissues, and for the (in)direct delivery of defined genes and their integration and expression in plant cells (Vasil, 1996:702). Crop protection is without doubt one of the most important areas for biotechnology. Protecting crops against pests and diseases during growth or storage is a US$20 billion industry based largely on the use of chemical pesticides (Price, 1995:61). Recently, despite European opposition, Monsanto's Roundup Ready soya is being shipped into Europe for use in a range of food products (*Le Monde*, 1996; *Independent*, 1997).

Animal biotechnology is expected to have an enormous impact upon agro-food systems in the next few years (NABC, 1992; Grace, 1997).[18] The main areas where development is taking place include the following: animal quality in terms of production performance or the controlled expression of introduced foreign genes; animal health with respect to disease resistance; and animal welfare by diagnosis of management stress effects (OECD, 1992:62). Even though transgenic animals are the focus of intense public debate over genetic modification, it is suggested that one of the

[18] Biotechnology is also considered to have enormous potential for fish-farming (Grace, 1997:174-7).

advantages with the use of rDNA technology is that they facilitate specific and relatively large genetic alterations (Jones and Cordle, 1995:240). The first demonstration that such animals could be produced was in the early 1980s with mice (T. Smith, 1994:680). They were used to explore the enhancement of production traits to confer parasitic or disease resistance, and to produce novel or modified proteins (Dörnenburg and Lang-Hinrich, 1994:509). Controversially, these advances with mice have been translated onto larger animals (T. Smith, 1994:681); for example, in February 1997, Dolly the lamb, became the first mammal to be cloned from the tissue of an adult animal (*Economist*, 1997b; Gordon, 1997; Hodgson, 1997b).

Probably the first and most wide-spread application of biotechnology in animal agriculture is the use of somatotropins, or growth hormones, to enhance the efficiency of protein production in livestock (Caspari and Neville-Rolfe, 1989; Schneiderman, 1990:469; Buttel, 1998). The GM gene Bovine Somatotropin (BST) stimulates greater milk yield by diverting feed nutrient to the mammary glands, and is said to boost milk yield by more than 10 percent (Caspari and Neville-Rolfe, 1989:45; *Guardian*, 1994). However, recent evidence also suggests that BST leads to a decline in the cow's health as it raises its body temperature (Millstone *et al.*, 1994). Although BST has been cleared by some countries such as South Africa, Brazil, Mexico and the former Soviet Union, it has been banned in the EU (in part) because of pressure from the farming and consumer lobbies (Price, 1995:72). Ironically, further development in rDNA technology may lead to cows being genetically altered to produce more BST themselves eliminating the need to inject the synthetic hormone (Grace, 1997:105).

3.3.2 Processing aids

It is easily forgotten that the most important developments in agro-food biotechnology will probably involve humbler elements such as food processing aids (Price, 1995: Madden, 1995). For instance, in the area of biopreservation, rDNA technology is already being developed and applied in biological systems or adapted to food micro-organisms in order to provide preservation capabilities in foods in place of synthetic chemical preservatives (OECD, 1992:92). A case in point involves lactic bacteria which are widely used in food products, particularly in diary products such as

cheese, cured meats and flavour products. Some lactic bacteria have unusual anti-microbial activities, and if these can be genetically modified and used in preservation purposes, they could be incorporated safely into certain foods where they could provide specific protection against undesirable food poisoning bacteria such as listeria, botulism and *Escerichia coli 0157*.[19]

Another food processing aid which can be produced by rDNA technology involves the development and utilisation of testing procedures used to detect undesirable, and frequently harmful, toxins and other biological or chemical contaminants (Cross, 1992:122; OECD, 1992:93; Hodgson, 1997a:3). Micro-biological contaminants, such as salmonella and listeria, pose substantial problems to food manufacturers and agents involved in public safety. In the UK, for instance, there are on average 200 cases of serious food poisoning per day (*Independent*, 1998b). Currently, the testing methods used to identify salmonella takes on average four to six days and, therefore, are of limited value for control purposes or 'real-time' decision making (DTI, 1995b:11). However, with advancements in rDNA technology, the potential for a complete reshaping of this area is emerging. For example, the antigenic structure of salmonella can be constructed allowing individual strains of salmonella to be recognised, which can then be built into fast reacting colour detection schemes such as the ELISA technique, which dramatically shorten the time for analysis (OECD, 1992:92).

But the most important food processing aids to emerge in recent years using genetic modification involve enzymes.[20] Enzymes are proteins which act as biocatalysts in living organisms initiating and accelerating a wide range of reactions and are widely used in the food and drink industry (La Roche, 1992:50). It can be argued that biotechnology is essentially about enzymes and the way they can be used in food and drink manufacture (Tombs, 1990:4). For instance, they are used in the production of food ingredients, such as *Glucose isomerase*, in the manufacture of high fructose corn

---

[19] *Escherichia coli 0157* was responsible for a disease which recently became a growing public health problem in Scotland. Whilst biotechnology is seen to offer some prospects of treating this condition (Hodgson, 1997a), it is worth noting that simple handwashing provides an effective means of preventing transmission from contaminated materials to food (Eley, 1997).

[20] Consequently, the main qualitative element of this research concentrates on the innovation of GMEs.

syrup (HFCS), and in food processing, such as *Pectinases* used in the clarification of fruit juices. Only a small number of large volume enzymes have been produced in the past, but rDNA technology is making it possible to produce enzymes in larger quantities, and to modify their primary structures, altering their physio-chemical and biological characteristics (Katchalski-Katzir, 1993:471). In recent years, the use of rDNA technology has seen some important developments in enzymes (K. Smith, 1994:264), and GMEs now account for over 50 percent of the industrial enzyme market (Hodgson, 1994:789).[21] The current global enzyme market is around US$1.4 billion and rising by over 10 percent in sales volume with a value increase of 4-5 percent per annum (Cowan, 1996:177).[22] The food industry accounts for over 50 percent of all commercial enzymes and will continue to be a major market in future (Dekker, 1994). Critically, although the value of the market for enzymes is relatively small, the 'value added' capability of biotechnology is enormous.[23] At present, the use of enzyme technology is still seen to have many limitations including the loss of enzyme activity, high costs and the need for significant capital investment (K. Smith, 1994:264). Nevertheless, these limitations are being overcome by increasing the efficiency of enzyme extraction, adopting rDNA technology to produce inexpensive enzymes, and immobilising rare and expensive enzymes which make them insoluble in water (Taylor, 1993).

3.3.3 Food material

Food quality improvements, such as extending shelf life, increasing solids content, and improving protein and oil quality, are important areas where biotechnology is having an impact and is characterised by the most frequently tested field applications (Beck and Ulrich, 1993:895). For example, the Flavr Savr™ tomato, developed by Calgene, which has been modified for better ripening on the vine, is now available all year round and was the first GM food to be approved for consumption in America (Dörnenburg and Lang-Hinrichs, 1994:509). Tomatoes and other soft fruits are

---

[21] This figure is probably considerably higher now (see **Section 5.2.2**).

[22] The discrepancy between these two figures is attributed to the tendency of successful enzymes to acquire commodity status rapidly, where prices and profit margins shrink as a result of increasing competition (Cowan, 1996:177).

[23] Indeed, given the pivotal role of enzymes in food processing, and the fact that roughly 85 percent of food consumed in Britain is processed (BMA, 1986:26), it is reasonable to suggest that the role of enzymes in adding value to the food production process is considerable.

usually picked while still under ripe so that they remain firm during transportation to food retailers. The modified tomatoes have had their softening gene 'switched off' by making a copy of the gene responsible for the softening enzyme, polygalacturonse, and then turned around and inserted back into the tomato so that it blocks the message that 'switches on' the softening process (FDF, 1996b). The result is that tomatoes can ripen on the vine until they have their full flavour and colour but still remain firm for harvesting leading to less waste and flexibility during harvesting. Zeneca Plant Science have also developed a crop of GM tomatoes which slows down the action of the enzyme which causes the fruit to rot (DTI, 1996c). Unlike Calgene's Flavr Savr™ tomato, Zeneca's has been used in the UK in the form of tomato purée (*Guardian*, 1997a). Importantly, Zeneca have expressed the view that developments in this research are likely to be transferable to many other fruits and vegetables (Russell, 1994:24).

Biotechnology also promises to produce new and cheaper varieties of food and drink with better quality, taste and nutritional features (NEDC, 1991; WHO, 1991; MAFF, 1994; NCCPB, 1994; EFB, 1994; Madden, 1995). For example, Quorn, a mycelium fungus (myco-protein) grown on a glucose substrate (usually waste from the petro-chemical industry) has been produced by a company jointly owned by Imperial Chemical Industries (ICI) and Rank Hovis McDougall (RHM) (OECD, 1992:94; Howells, 1994:21). Quorn is currently being sold in the UK in a range of products, although unlike meat dishes - lasagne, for example - they can carry a vegetarian label and they can be made without animal fats, which is attractive to some consumers (Hewitt, 1994).

Another area where biotechnology is used specifically to produce foods for direct consumption involves a number of 'functional foods'. These are especially popular in Japan and include products such as oligosacchardes for low insulin-low calorie response, non-carcinogenic diasaccarides, designer fats (J. Smith, 1994:265; Hollingsworth, 1995; Hasler, 1998). Yakult,[24] for example, which was developed in Japan in the 1930s, contains a lactic acid bacterium which is naturally present in the intestinal flora of humans and which plays an important role in resistance against pathogenic bacteria (Darrington, 1995). More generally, biotechnology is used to

[24] Yakult is Esperanto for yoghurt. Leaving aside its potential health benefits, it is also worth pointing out that Yakult has a fair amount of sugar to make up for the sour taste (*Observer*, 1996).

enhance the nutritive quality of fruit and vegetables, develop synthetic fat substitutes and produce leaner beef products that may reduce incidence of diet related health problems (DRHPs) (Bills and Kung, 1992; Greenwald, 1992). For example, as better information is gained about the metabolism of particular fats, the possibility of producing specific fatty acid ratios emerges (Katz, 1996:65). Researchers at Calgene are looking for the DNA in fats with less hydrocarbons (and thus are healthier) and inserting it into rape from where oil rich in short-chain fatty acids may be extracted (*Economist*, 1996a).

3.3.4 Waste material

The application of rDNA technology to waste management is potentially enormous (Sharp, 1995:175; Grace, 1997:134-9). The use of GMEs as food processing aids has been outlined already. Another important use for GMEs is in their application to waste water from food and drink production (OECD, 1989:28; Towalski and Rothman, 1995:111), frequently to remove one particular waste component (NEDC, 1991:45). A familiar example of this type of technology is the domestic biological detergent which uses enzymes from the organism *Bacillus subtillis* to break down protein-based strains (Price, 1995:19). GMEs can also be used in the development of biosensors for the detection of agrochemical residues in water and food waste. The technique is based on the interaction of a GME with a particular target chemical (OECD, 1992:112; Grace, 1997:134).

A further application of biotechnology for the treatment of waste in agro-food systems centres on the production and use of whey. Cheese production is characterised by the separation and concentration of protein from milk using acid preparations (Angold et al., 1989:36). When a hard cheese is formed, up to 90 percent of the original volume of the milk is left in the form of whey. Traditionally, whey has been used as animal feed but its disposal has become a costly business averaging about £20 per tonne of cheese produced (ibid.).Whilst much of the whey is wasted, a number of processes are being developed centred on the separation of solids. These include hydrolysing the whey using GMEs so that the whey is formed

into a syrup and then used in the manufacture of confectionery and ice cream (ibid.:37).

3.3.5 Environment

As well as in the treatment of waste, biotechnology can also be used to minimise chemical inputs in agro-food systems (OECD, 1992:112; Roobeek, 1995:75; Grace, 1997:112-4). Modern plant production is highly dependent on fertilisers and many high yielding varieties of plant will not grow without the addition of fertilisers (Price, 1995:73). For example, plants need nitrogen to grow and attempts have been made to enhance the availability of nitrogen (FDF, 1995b:13). One approach involves the use of *Rhizobium spp.* bacteria that occur naturally in a symbiotic relationship with leguminous plants species such as Alfalfa (Mannion, 1995:35). These bacteria can take the nitrogen from the air and convert it for use in plant growth. Current research aims to modify this bacteria genetically so that it can live in the roots of cereal crops providing a ready-made source of nitrogen (Schneiderman, 1990:467). Other bacteria, micro-organisms and fungi can be used to provide useful compounds other than nitrogen in the soil to aid growth and combat disease, and a few, such as the *mycorrhizal* fungi that help phosphate accumulation, have been genetically modified (OECD, 1992:50).

Moreover, ever since Rachel Carson published 'Silent Spring' (1965) which highlighted the dangers of chemical pesticides, there has been a search for alternatives to chemicals.[25] Biological control involves the use of a pest's natural predators in place of chemicals. Although not yet widespread in agriculture, biological control is used increasingly as a selling point. For instance, Tesco the UK food retailer, makes a point of advising customers that 'natural' predators are used to control pests (Price, 1995:62).[26] Biopesticides use naturally occurring substances, usually insecticides, which have the advantage over some synthetic materials in that they are readily biodegradable. Much biopesticide research is concerned with the toxin produced by the bacterium *Bacillus thuringiensis* (Bt). This substance is a protein produced by some strains of the organism

[25] This reflects an earlier point made in **Section 3.2** about the ascendancy of the biological sciences.

[26] Sainsbury's, another UK food retailer, has also started emphasising the use of 'natural ways' to protect crops (*Guardian*, 1998d).

and is lethal to pests such as caterpillars, flies and beetles. The gene(s) that control the toxin have been identified and introduced with success into tomatoes, maize, tobacco and cotton (Mannion, 1995:36). For example, Ciba Geigy,[27] a Swiss pharmaceutical company, has developed a new maize which makes it resistant to the European corn borer (*Economist*, 1996b).

To conclude this general description of agro-food biotechnology two points need to be emphasised. First, whilst it is unreasonable to suggest that we are still at the beginning of the development and application of rDNA technology to agro-food systems, it is difficult to foretell the developments in this sector from the literature. Nevertheless, given that the developmental trajectories of agro-food biotechnology will not take place in a vacuum, further work remains to be done on identifying the differences between *actual* and *potential* developments. Second, the reservations about the description of the main aspects of agro-food biotechnology notwithstanding, it is reasonable to assert that identifying and analysing developments in this sector remains an important field of enquiry.

3.4 Summary

Organised around the question 'What is (agro-food) biotechnology?', this chapter, in contrast to the last, outlines the more obviously practical elements of (agro-food) biotechnology. It is argued that despite its long history, 'modern' biotechnology is more usefully considered as being significantly different from 'traditional' developments. Given this, and given that only a partial review of biotechnology is provided - key areas such as pharmaceuticals and human health care are not considered - it is suggested that developments in agro-food biotechnology cannot be ignored. Using a 'systems' approach which focuses attention on both products and processes, key aspects of agro-food biotechnology are described. Whilst a sense of the enormous potential of agro-food biotechnology is invoked, it remains uncertain how this will translate into reality (see **Chapter 1**). Having provided a bridge between the analytical part of this thesis and the empirical data to come, it is

[27] Ciba Geigy has now merged with Sandoz to form Novartis (*Nature biotechnology*, 1997a).

important to consider how innovation in agro-food biotechnology can be examined. The next chapter looks at the research techniques employed.

4

ON METHOD

4.1 Introduction

Ideas about method fall into two separate but interconnected categories: epistemological and technical. In epistemological terms, ideas about method deal largely with the foundation of knowledge, that is, how knowledge is constructed, construed and used in research projects. In this sense, method is mainly a philosophical consideration and is a central focus of research for (*inter alia*) philosophers of science and technology (see, for example, Ellul, 1965, Popper, 1968; Lakatos, 1968; Kuhn, 1970; Heidegger, 1977; Feyerabend, 1993). By contrast, ideas about method also cover research techniques; for instance, how is research to be organised and managed in order to tackle the main research questions in hand?

Analytically it is possible to separate the epistemological from the technical, even if the former strongly influences the latter.[1] These connections are not considered here (see Cohen and Wartofsky, 1983). Instead the emphasis is on outlining research techniques. The chapter has three main parts. **Section 4.2** presents some general points about research techniques available to the researcher. In **Section 4.3**, the first part of the fieldwork, which involves surveying and analytical techniques to explore general issues, is described. **Section 4.4** outlines the more substantial part of the fieldwork. Organised around an in-depth investigation of innovation of GMEs, this part of the chapter presents the main aspects of the interview-based research techniques used. Taking these three sections together, the chapter presents an account of how the research engaged with the conceptualisation of biotechnological innovation developed in **Chapter 2**.

[1] For useful discussions of some of the epistemological issues connected to method see Chalmers (1988) and Webb (1995).

4.2 Research techniques

The research techniques employed are based on a number of premises which relate to the theoretical and empirical framework outlined in **Chapters 2** and 3. Choice of methodologies in the social sciences is frequently construed in terms of the quantitative-qualitative debate (Mostyn, 1985; Winchester, 1996). Whilst the sharp categorical distinction between quantitative and qualitative methods helps elucidate concerns with the unreasoned application of quantification (see Johnston, 1980), it also tends to over-simplify by suggesting that quantitative and qualitative methods are binary oppositions and, therefore, mutually exclusive. This opposition is rejected here, a position well established in studies of technological innovation (see, for example, Hippel von, 1988; Winch, 1994; McKelvey, 1996).

Before outlining the main techniques devised, three points need to be made. First, whilst the description of the techniques used to investigate (bio)technological innovation tends to make the study design appear linear, in practice the research programme did not work like this. To borrow an idea from Kuhn (1970:138-140), the research design was essentially 'recursive'. It involved an iterative process between the literature and individuals involved in the project. Second, important elements such as desk research and literature reviews are not elaborated upon in this chapter as they are considered general features of research practice. Third, it is important to acknowledge that the development of research techniques took place in parallel, and in relation to, changes with theoretical concerns and the research questions (see **Chapter 1**). Originally, the research sought to combine an investigation of innovation in agro-food biotechnology with an understanding of food provision in the UK. It pivoted on how biotechnology impacts upon the nutritional status of individuals. At that stage, a four-fold methodology seemed appropriate: a survey of key individuals involved in the development, application, regulation and management of agro-food biotechnology; the construction of a 'novel foods' database; an analysis of the National Food Survey (NFS) to shed light on consumption patterns linked to developments in agro-food biotechnology; and an ethnographic account of biotechnological innovation organised around a number of case studies. However, it became apparent that the 'nutrition-health' dimension of the study was problematic for four reasons. First, DRHPs are

multifactorial and it is difficult to identify cause and effect relations between food consumption and health. Second, nutrition is a highly contextualised process and cannot be considered simply in terms of food consumption patterns identified from the NFS. Third, despite the breadth of information provided by the NFS, it is not significantly specific to allow accurate links to be made between foods produced using agro-food biotechnology and health. And fourth, in order to make the project workable it was considered easier to explore the 'nature' of agro-food biotechnology from a single vantage point. These considerations led to the conclusion that only one aspect should be focused upon: the innovation process itself. A dual strategy incorporating both surveying and interviewing techniques was duly developed.[2]

4.3 Surveying

Surveys are an important methodological tool for social scientists as they allow large quantities of data to be gathered in a relatively easy and systematic way (Oppenheim, 1992). In the study of technological innovation, recent examples of research employing survey techniques include the importance of knowledge acquisition and transfer through innovation networks (Newell and Swan, 1995); identifying and assessing the technological and non-technological importance of a 'technological strategy' (Lowe and Taylor, 1996); the influence of 'short-termism' on the innovation process (Demirag, 1996); the relevance of social networks of managers for innovation (Carroll and Teo, 1996); and the class and gender implications of changes that are taking place within the City of London (McDowell, 1997). In this study, a survey is seen as especially beneficial because it provides the opportunity to collect data where little information exists. It is used to examine the

[2] Clearly, the approach employed is not the only one available. For example, one of the most popular methods used to investigate technological innovation is longitudinal study. Longitudinal studies are an example of 'ethnographic' work and provide the opportunity for understanding the world as they are 'experienced' (Cooke and Crang, 1995; cf. Hammersley, 1992). Examples of ethnographic accounts of R&D include Traweek's (1988) study of the world of high energy physics, Law's (1994) account of R&D in a government laboratory, and Rabinow's (1996) work on the development of polymerase chain reaction (PCR). But whilst ethnographic accounts are a useful research technique, given the constraints of time and gaining access to relevant arenas for long periods (it took 10 years to develop the GM chymosin!) they were not considered appropriate to this study.

actual and potential developments in agro-food biotechnology and to act as an entry point for a more in-depth investigation of innovation.

The survey consists of a self-administered postal questionnaire sent to R&D managers in the UK. The persons surveyed constitute key members of the UK biotechnological innovation milieu. They do not comprise a random sample of individuals in organisations, and should not be considered a representative sample of attitudes across the entire biotechnology sector. The utility of this group of individuals lies in their influence on innovation in biotechnology in the UK. Two questionnaires were sent in early 1996 to just over 100 organisations representing the main interests involved in developing, applying, regulating and stimulating agro-food biotechnology. The idea behind sending two questionnaires to each organisation was to try to obtain comparable data from two different respondents within an organisation on the assumption that there are any discernible differences in opinion. The sample was drawn largely from an international biotechnology R&D directory (Coombs and Alston, 1995), and is sufficiently diverse to reflect the different stages and interests in the agro-food system.[3] The Directory is organised according to country and provides details on the address/telephone number, as well as a brief description of the main area of R&D in biotechnology each organisation is involved in. A total of 145 UK organisations were identified. Given the potential inaccuracy of trade directories, each case was screened by telephone, to check whether they were still engaged in the R&D aspect of innovation in agro-food biotechnology, and to identify names of individuals who would meet the specific criteria of having an understanding of the innovation activities in the organisation.[4] Importantly, telephone contact also provided the opportunity to explain briefly the aims of the questionnaire and, by extension, encourage co-operation.[5] After screening, 97 organisations were left and when combined with the major food multiples made a sample of just over 100. A pre-paid envelope with the return address was included with the questionnaire together with a letter indicating

[3] Organisations not drawn from the Directory include the major food retailers and government institutions.
[4] Leaving aside the fact that in recent years the area codes in the UK have frequently changed, the 'out-of-date' nature of the Directory (possibly by two years) also reflects the rapid structural and organisational changes taking place in (agro-food) biotechnology.
[5] Having said that, I did not get to speak to about a half of the potential respondents as my calls were often successfully screened by their 'gate-keepers'.

the purpose of the questionnaire, and reaffirming the confidentiality of the information and its use for academic research purposes only (see **Appendix A**).

Before being sent out, the questionnaire was piloted in two stages with 10 R&D managers, directors and scientists. The first stage entailed piloting through a number of biotechnology related Internet mailing lists, such as BizBiotech and Biotechnology. This aspect of piloting involved sending the questionnaire with a short covering letter to other subscribers on these mailing lists. Whilst there were several drawbacks with this technique,[6] the Internet proved an easy and cheap means of piloting the questionnaire. What is more, it was effective in that a number of key concerns with the questionnaire were raised and rectified. Following the pilot on the Internet, the questionnaire was piloted with two senior research scientists at the Centre for Biochemical Engineering at University College London (UCL). As a result, a number of questions were revised. To increase the response rate, follow up telephone calls were conducted 10 days after the questionnaires had been sent.[7]

The questionnaire consisted of both open and closed questions (see **Appendix A**). The closed questions generally involved a Likert scale (for example, 1 = Least important and 5 = Most important). The open questions were designed to

---

[6] Although most of the subscribers (and respondents) were from the United States, they nevertheless were able to make positive comments about the structure and format of the questionnaire. It must be said, though, that whilst the questionnaire was being piloted, I received on average 50 irrelevant messages a day reflecting the growing (ab)use of the Internet.

[7] I thought about a number of ways to increase the response rate. One unsuccessful attempt at increasing the response rate of my questionnaire involved trying to obtain the support of the DTI. From the outset, I felt that if the DTI endorsed my questionnaire this would have given it more weight and, by extension, improve the response rate (of course, one could argue that the DTI's endorsement may have deterred respondents because of concerns over commercial confidentiality). The obvious place to start was with the DTI's Biotechnology Means Business (BMB) ECU 11.8 million initiative launched in March 1995. The BMB aims to increase awareness amongst UK industry of the opportunities biotechnology presents, and helps companies to use biotechnology for increased profitability and competitiveness (Ernst & Young, 1996). Given the scope and resources behind the BMB, I felt it would be an excellent way to promote my questionnaire (perhaps by using the BMB logo on my covering letters). Following contact with the BMB initiative, it turned out that my request had been passed onto Defacto, a private marketing company who managed the programme. Whilst Defacto seemed enthusiastic about the project, they needed to get approval from the DTI. After going through several levels of bureaucracy, I was told that it had reached ministerial level. And whilst it was likely to be approved, I had to wait about six months for the process to be finalised. Given this, and given that the process had already taken three months, I dropped my request in order to prevent further delay.

test some of the more general concepts of interest in this study, and to allow freedom of thought and expression for the respondents. Of the 200 questionnaires sent out, 45 were returned giving a response rate of just under 23 percent for individuals; the response rate for organisations, however, was considerably higher at 40 percent reflecting the infrequency of more than one questionnaire being returned per organisation (see **Table 4.1** for a breakdown of the organisational profile of respondents).[8] This relatively low level of response, although disappointing, is not considered unusual for this type of survey; for example, in a survey conducted by the CEC (1989:9) on the impact of biotechnology on agriculture, a response rate of just over 20 percent was achieved.

Table 4.1: Organisational profile of respondents

Type	Number of responses	Percentage of responses
DBFs	14	31
Universities/public research	10	22
Food & drink manufacturers	8	18
Retailers	5	11
Agricultural interests	3	7
Government agencies	3	7
Other	2	4

Total number of responses (n) = 45

There are a number of possible reasons for this relatively low response rate. First, whilst it was difficult to obtain any appropriate figures, many organisations have a policy of not responding to surveys. Second, despite assurances (both written and verbal) of complete confidentiality, it is possible that some commercial organisations are reluctant to disclose in any detail the nature of their research.[9] Third, a lack of time (or perhaps inclination) to respond is also relevant especially as the current explosion of interest in biotechnology is resulting in extensive research and analysis. Management consultants are especially active. For instance, Arthur Andersen (1994:209) have set up The Andersen BioIndex which tracks the performance of biotechnology shares and compares their performance with those of

[8] To comply with a confidentiality agreement (see **Appendix A**) the individuals and/organisations are generally not identified by name in this thesis.
[9] No blank refusals were received.

the FTSE 100 and the FT Actuaries' Pharmaceutical and Healthcare Indices; similarly Ernst & Young have created a separate biotechnology practice which publishes reports on the state of the biotechnology industry based on industry surveys (Ernst & Young 1994, 1996, 1998).[10]

Mindful of the need to keep the questionnaire short (anticipated completion time 15-20 minutes), it was restricted to eight pages (see **Appendix A**). It was divided into three main sections. The first, dealt with general questions about the respondent and the organisation. Whilst elements of this section - where the HQ is based, for instance - are now not considered crucial for the main arguments of this thesis, it was felt to be a useful means of introducing the respondent to the questionnaire. The second section covered developments in agro-food biotechnology.[11] One of the aims of this section, given the potential developments in the sector (see **Chapter 3**), was to provide a perspective on developments taking place and the multi-/inter-disciplinary character of the research being undertaken. In the final section, some questions about the nature of innovation were asked.

It was assumed that some form of statistical and data analysis would be undertaken using the Statistical Package for Social Scientists (SPSS),[12] but given the relatively small number of responses it is not possible to undertake a comprehensive statistical analysis, although general observations can be made. These are discussed in later chapters.

---

[10] Whilst undertaking the survey, I was informed by one respondent that Arthur Andersen had sent out a 27 page questionnaire on biotechnology at the same time as mine.

[11] Whilst in the questionnaire I used the term 'agri', I now prefer to use 'agro' to refer to the agricultural elements of agro-food system. The literature has not been especially useful in trying to provide some reasoning behind the difference between them. One possible difference is that 'agro' appears to incorporate notions to do with the industrialisation of agriculture and large transnational agro-food concerns better than 'agri' because it seems to be limited less to *agri*culture. This difference notwithstanding, consistency in this thesis is the most important issue that needs to be acknowledged.

[12] For a guide to analysing survey data see Bryman and Cramer (1992).

4.4 Interviewing

Following **Chapter 2**, the main research design sought to engage with identifying and analysing networks. To borrow an idea from Latour (1997a:9), the research design is not about 'traced networks but about network-tracing'. This study, however, does not seek to undertake an 'actor-network' study of biotechnological innovation. Rather, it uses networks as analytical tools which link 'social' and 'technological' elements together and cross-cut organisations, regions and nations (see **Section 2.5**). But it was not especially clear how networks were to be investigated. The literature on the methodologies of ANT is limited (Davies, 1997:73).[13] For instance, the notion that we 'must follow the actors in order to identify the manner in which they define and associate the different elements by which they build and explain their world' (Latour, 1991:117), although attractive, raises questions about where to begin finding solutions and ending the analysis. This difficulty is not helped by the fact that much of the empirical work of actor-network theorists has taken place within confined laboratory spaces where clear boundaries can be set (see, for instance, Latour, 1987; Law, 1994; Cussins, 1998). In reply, Latour (1988:10, in Davies, 1997:77) remarks that the:

> 'fact that we do not know in advance what the world is made up of is not a reason for refusing to make a start, because other storytellers seem to know and are constantly defining actors that surround them - what they want, what causes them, and the ways in which they can be weakened or linked together. These storytellers attribute causes, date events, endow entities with qualities, classify actors. The analyst does not need to know more than they; (s)he has only to begin at a point, by recording what each actor says of the other.[...] The only task of the analyst is to follow the transformations that the actors convened in the stories are undergoing.'

But in practical terms, questions still remain on where to begin and end this analysis, which actors to follow, and how they are to be investigated. Generally, ANT implies some form of qualitative approach using either individual, or a combination of, ethnographic and interview-based approaches (Davies, 1997:74). Ethnographic studies usually imply an intensive, ongoing involvement with

---

[13] As noted in **Section 2.5**, given the limited literature on methodology, it is reasonable to question what an 'actor-network' study involves. There are many examples of research which have adopted perspectives from ANT (see, for example, Callon, 1986a; Law, 1994). Apart from the importance of case studies it is difficult to identify any general practical elements of a research methodology. To reiterate an earlier point, then, the usefulness of ANT in this study is on the centrality of 'networks' it accords.

individuals functioning in their everyday setting (Schofield, 1993:213). But whilst ethnographic approaches are seen to be useful for gaining detail about a particular issue (for a review, see Cook and Crang, 1995), given the problems of gaining access to commercially sensitive areas (Bryman, 1988), and the constraints of time, they were seen as less appropriate for this study (see also **footnote 2** in this chapter).

Instead, interview-based techniques were seen as more suitable. They have become increasingly popular in social science (Eyles, 1988). Recent examples in the study of technological innovation include the importance of professional organisations in helping to disseminate information on technological innovation (Miller et al., 1995; Swan and Newell, 1995); the significance of information systems for both organisational structures and the ability to innovate (Jordan and Tricker, 1995); and how managers make sense of the business environment (Kim and Mauborgne, 1997). Interview-based studies are often organised around case studies. Case studies are a useful means of obtaining data about processes and socio-economic activity, such as technological innovation (Mitchell, 1983; Yin, 1994). And whilst it is hard to make general claims from them, case studies can help identify general trends. Examples of case studies used by actor-network theorists include: the scientific controversy in France over the farming of scallops (Callon, 1986a); the development of the tactical strike aircraft TSR2 in Britain (Law, 1988); the conventional character of cartographic representation (Turnball, 1993); the organisation and management of a large scientific laboratory (Law, 1994); the geographies of electrification in Denmark (Hinchliffe, 1996); and the formation of natural history documentaries (Davies, 1997).

The interviews were organised around the biotechnological innovation of GMEs. The choice of GMEs was influenced by two main factors. First, given the history of biotechnology, it was seen as essential to concentrate on the more recent developments associated with rDNA technology (see **Section 3.3**). Second, despite the continuing tendency of research to focus on the potentially more spectacular elements of biotechnology, such as the 'oncomouse' or 'frankenfoods' (Haraway, 1992; 1997; Wilkie, 1996), it was considered more appropriate to investigate an

aspect of rDNA technology which was currently commercially available and in widespread use (Ahson 1996b).

The innovation of GMEs is dominated by a small number of firms of which Danish and Dutch companies play an especially prominent role. Whilst difficult to get reliable figures, Chr Hansen and Novo Nordisk[14] (Denmark) and Gist-brocades and Quest (the Netherlands) together account for over 70 percent of the enzymes used in Europe (Llewellyn, 1988). More generally, Danish and Dutch organisations figure strongly in biotechnology across the world. In Denmark there are 175 organisations involved in biotechnology, in the Netherlands 416 (Coombs and Alston, 1995). Why Danish and Dutch companies figure so strongly in biotechnological innovation is an interesting question.[15] Six reasons might help to explain this.[16] First, both Denmark and the Netherlands have strong traditions in more traditional forms of biotechnology, such as brewing and plant breeding (Bennet, 1998; Kraft, 1998). For example, the large Carlsberg breweries in Denmark date from 1847, and the Christian Hansen Laboratories which manufacture food processing aids for the diary industry, from 1874. In the Netherlands, the fermentation company Gist brocades has been producing baker's yeast and alcohol since the 1870s. Both countries also have a long tradition in the development and production of advanced chemicals which has has a considerable influence on developments in biotechnology (see **Section 3.2**). For instance, in the Netherlands, AKZO Nobel and DSM are dominant world players in the manufacture of specialist chemicals, such as those used in fertilisers and pesticides.[17] Similarly, in Denmark, Novo Nordisk has extensive commercial interests in the human insulin market.

---

[14] Novo Nordisk is perhaps the largest biotechnology company in the world (Ernst & Young, 1996). In 1994, the Novo Group had a gross profit of DKK 3521 million, of which DKK 1202 million was from the company, with the enzyme business sales - the most important - increasing by 8 percent (Novo Nordisk, 1995). In Denmark it accounts for over 60 percent of total biotechnology research capacity (Kraft, 1998).

[15] More generally, according to IMD (1996) the Swiss management institute, Denmark and the Netherlands occupied fifth and seventh positions respectively based on the competitiveness of their industries. By contrast, the competitiveness of the UK dropped from fifteenth in 1995 to nineteenth in 1996.

[16] Reasons for the prominence of Danish and Dutch firms could be extended even further to include the wider socio-economic context. In order to prevent a sense that this study is a comparison between biotechnology in Denmark and the Netherlands, an outline of these wider reasons is avoided.

[17] DSM recently acquired Gist brocades for $1.4 billion to improve its capabilities in the manufacture of antibiotics (*Nature biotechnology*, 1998a).

Finally, both Denmark and the Netherlands are host to a number of large food multinationals, such as Danisco and Unilever, which from an early stage in their histories have recognised the importance of rDNA technology for the provision of food.

Second, government support is a prominent feature of the Danish and Dutch biotechnology sectors. Denmark, for example, spends more public money per capita on biotechnology research than any other country in the world (CC, 1996:10). At the heart of Danish attempts to stimulate the biotechnology sector have been a series of research programmes designed to encourage technological innovation. The first Danish biotechnology programme (1987-90), endowed with DKK 381 million, was set up to develop the R&D and educational system (Forskningdirektoratet, 1990:19). The second biotechnology programme (1991-95), endowed with DKK 463 million, aimed to build on the previous programme by sustaining and improving Danish research (DRC, 1993). The Dutch government for their part spent more than Dfl 400 million between 1981 and 1993 on measures to stimulate Dutch biotechnology (NFIA, 1995).

Third, both Denmark and the Netherlands have good prospects for capital investment. Despite the UK dominance of capital investment in European biotechnology (Ernst & Young, 1996, 1998), both Denmark and the Netherlands can boast substantial records of private investment in biotechnology. In Denmark, for instance, the recent success of biotechnology products in the health care industry is leading to a large number of DBFs acquring funds (Kraft, 1998). Similarly, in the Netherlands, venture capital for biotechnology is almost as readily available in the UK as highlighted by the raising of Dfl 28.1 million by the Dutch DBF IntroGene which was the fifth largest private placing of funds in a DBF in Europe in 1997 (Bennet, 1998).

A fourth important feature is the extent to which stimulation of the biotechnology sector has focused on universities and research institutions, leading to a big increase in both the volume and quality of research. In Denmark, for instance, two of the main objectives behind the first biotechnology programme are to ensure the supply of an adequate number of PhD candidates and to create more

effective co-operation between the public and private sectors (Forskningdirektoratet, 1990:19). Additionally, the Programme aims to strengthen international co-operation and to ensure that Danish research in biotechnology is carried out to high international standards. In the Netherlands, this desire to maintain high standards is linked to the high participation in EU programmes on biotechnology (NFIA, 1995:12). In addition, the Association of Biotechnology Graduate Schools in the Netherlands (ABON) has set up a research network to provide a focus for post-graduate training and research which will improve the overall standard of innovation in biotechnology (Bennet, 1998).

Fifth, both Denmark and the Netherlands have strong regulatory environments in biotechnology (OECD, 1992; Thomas, 1993; Ernst & Young, 1994), but ones which do not necessarily have a negative impact on innovation.[18] In 1986, Denmark was the first country to set up a specific law for biotechnology which regulates the use of human genes but also provides a regulatory framework which permits the use of rDNA technology (Terney, 1996). Whilst these specific gene laws are continually reviewed and up-dated in light of developments in rDNA technology, they are not considered a hurdle for biotechnological innovation (Kraft, 1998). In the Netherlands, wider regulations have been put into place which ensure that genetic modification is safe for the environment and consumers, and comply with ethical norms when working with animals (NFIA, 1995:15). Importantly, in the Dutch case a regulatory environment has been developed which accommodates changes in developments in biotechnology (Bennet, 1998).

Finally, as with the regulatory environment, public acceptance is considered an important factor influencing the instigation and development of biotechnology R&D (Durant et al., 1992; NCCPB, 1994). According to a survey conducted by the CEC, 47 percent of respondents say that biotechnology would offer improvements to their lives (Marlier, 1992). However, the publics in both Denmark and the Netherlands hold negative attitudes towards products which do not have a clear positive benefit or raise ethical questions especially with regards to the use of animals. Consequently, and encouraged by the nature of national political systems,

[18] National regulations are soon to be subsumed or superseded by regulations at a European level. **Section 6.3.4** provides a brief review of European regulation relevant for biotechnology.

there is considerable dialogue between various interested parties in Denmark and the Netherlands. For example, the Danish, who pioneered the consensus conference method, held several on biotechnology (Teknologi-Rådet, 1995). In the Netherlands, there have been a number of projects designed to bring industrial and consumer organisations together. For example, Unilever, following the possible threat of a consumer boycott, initiated a series of talks with consumer groups and together with other companies and environmental groups set up the Informal Consultation Group on Biotechnology (NFIA, 1995:15). Crucially, the bringing together of all interested parties has not only been an example of good governance, but also a useful means of gauging the needs of the market generally and consumers particularly (Bennet, 1998).

Given the strengths, importance, and domination of the Danish and Dutch biotechnology sectors, especially in enzymes, it was logical to examine the biotechnological innovation of GMEs in these countries. Of course, as delineated by the adoption of the network as a particular spatial form, this did not entail a 'national' or 'regional' study as the networks extended to the UK where the GMEs were applied in the provision of food. Moreover, as emphasised earlier, focusing on the innovation in GMEs in these two countries does not constitute a comparative study as the choice of examining two GMEs is made on the grounds that there is uncertainty with the research techniques used to trace networks. That noted, there also remained uncertainty over where to start and how to organise the analysis. Enzyme manufacturers seemed like an obvious place to start the tracing of biotechnological innovation networks. Having made that decision, given that there is little guidance from actor-network theorists over where network tracing should begin, the GMEs themselves have been 'followed' - from enzyme manufacturers to consumers. This approach is based on the assumption that the GME is a product of a network and that this network spreads beyond laboratories in specific national/international contexts. But given the lack of insight from ANT on research methods, it was felt that a pilot study was required to address which GMEs to follow, and where.

4.4.1 Pilot study: in-depth interviews, phase I

R&D managers involved in the innovation of GMEs were considered to be the most appropriate starting point for the pilot study. Whilst in theoretical terms this raises interesting questions, especially on whether an understanding of biotechnological innovation would have been different if the GMEs were followed from the final consumers, the decision to begin with R&D managers was taken from a purely practical point of view. Given this decision, and given the fact that Danish and Dutch companies dominate the manufacture of GMEs, the pilot study concentrated on these sectors in these two countries. At an early stage issues arose about conducting research abroad. Generally, there is no reason to expect that conducting fieldwork 'abroad' is anymore problematic or difficult than at 'home'. But in the context of examining the innovation of GMEs, the constraints of time and resources (associated with a PhD) clearly need to be taken into account, and the pilot study was seen as an opportunity to test the method of 'following' GMEs and an opportunity to evaluate some of the concepts and hypotheses emerging from the postal questionnaire. Equally, in a practical sense, the pilot study aimed to identify cases of innovation of GMEs, and their context and contacts, for subsequent in-depth investigation.

The pilot study thus focused on R&D managers of organisations that developed agro-food biotechnology generally and GMEs specifically in Denmark and the Netherlands. Potential organisations were identified from the international biotechnology R&D directory used for the postal questionnaire (Coombs and Alston, 1995) and contacted by letter (see **Appendix B**). In the letter, written in English, the objectives of the research project and pilot study are outlined. In particular, the desire to discuss innovations in agro-food biotechnology, and to identify and evaluate the particularities of the Danish and Dutch (bio)technological innovation environments, especially with regards to the link between R&D and 'culture' were highlighted. The use of broad terms such as 'science' and 'culture' are employed to stimulate interest and to avoid potential interviewees being deterred by detail. The overall response rate was reasonable, with most of the key

organisations involved in innovation in GMEs agreeing to participate.[19] Out of the 15 positive responses, nine were considered to have direct relevance to GMEs in the agro-food system and interviews were organised; a further sixteen interviews were arranged with people whilst the pilot study was being undertaken. All 25 interviews were conducted privately in the interviewees' place of work between April and May 1996 and lasted between 30 and 60 minutes. Each of the interviews were taped and later carefully transcribed paying attention to transcribing the discussion accurately. The interviews were semi-structured and an interview schedule was used to maximise the effective use of time (see **Appendix B**). As part of the agreement to giving an interview, interviewees were assured of the confidentiality of the information and a copy of the interview transcript was provided for them to check and comment upon. A list of the interviewees is given in **Appendix D**.

Overall, the pilot study was successful. It led to a better idea of the actors involved and how the networks could be further investigated. Two GMEs emerged as possible cases for the central focus of the in-depth part of the study (see also **Section 6.3**). The first, a GM chymosin (enzyme X), is produced by a large well-established Danish enzyme manufacturer (firm A), and is used for the coagulation of milk in the production of cheese. Firm A has been involved in the production of cheese coagulants for over a century and is now one of the largest manufacturers of coagulants in the world. The second, a GM xylanase (enzyme Y), is produced by a large food ingredients company (firm C) based in the Netherlands. Firm C is part of a very large agro-food and consumer durable multinational (firm D). Enzyme Y is

[19] The response rate from Dutch companies was far more positive than for Danish ones: out of eighteen organisations contacted in Denmark only three replied positively to my initial letter, with another saying that they had closed down their R&D facilities (18 percent); by contrast, out of forty three letters to the Netherlands, twelve positive replies were received, and a further three from firms that had either closed or moved their R&D facilities (35 percent). Why exactly there was this discrepancy is not considered in any great detail here. Suffice to say, from my experience in both countries I was able to discern a slightly different attitude to 'foreigners'. To put it bluntly, as a Danish friend suggested, not having a particularly 'English name' may have deterred some respondents in Denmark. Many writers have written about the issue of 'identity' for researchers. Some of the more useful literature includes work dealing with gender (Oakley, 1981; Finch, 1984) and race (Kobayashi, 1994). Avoiding the temptation of elaborating on this issue, the identity of the researcher, both how it is constructed and viewed by others, needs to be taken into account. Perhaps Sartre's (1995) point about the 'poor man's snobbery' against 'outsiders' is a relevant one for explaining differences in response rates between countries.

used for the production of bread. Both these GMEs are well established in the enzyme market place and are used in the provision of food in the UK. Quite apart from the knowledge gained and contacts made, three other points arose which influenced the design of the subsequent research. The first, and in a way confirming previous assumptions, the networks did not appear to be limited to the organisations in question. Indeed, there was a range of other actors who seemed to be drawn into the innovation of GMEs. In this sense, the notion proposed by actor-network theorists of thinking about networks as a particular spatial form not captured by notions of levels, layers and territories, points to the appropriateness of an analysis that is not dominated by any current spatial logic (Latour, 1997a; Law, 1997a). A second matter arising from the pilot study was the clear indication that some of the elements which characterised the formation of networks would best be ignored. For instance, 'artefacts', such as laboratory notebooks, fermentation machines, flasks for experimentation, which could be viewed as mediating the development of networks were harder to investigate and less central to the analysis. Third, not all, or at least more than actually achieved, the individuals, organisations and actors in the networks could be interviewed as part of the investigation because of the constraints of time and resources. Because of this, a trade-off was made between the initial individuals interviewed in the network to provide the direction of the investigation, and the need to more actively 'chase' some elements of the network more than others to obtain a wider picture.

4.4.2 'Following' the GMEs: in-depth interviews, phase II

To ensure that sufficient material would be gathered it was considered useful to 'follow' both the GM chymosin and GM xylanase. These two GMEs provided interesting contrasts about the organisation of biotechnological innovation and helped overcome the dangers of not gathering sufficient data from one case study, especially given the difficulty in gaining access to key individuals and organisations in the commercial world for in-depth/ethnographic studies (Bryman, 1988; Robson, 1993; Law, 1994; Cook and Crang, 1995). In addition, the enthusiasm and willingness to co-operate shown by the research managers responsible for initiating and managing the innovation of these two GMEs was maximised as they

helped organise access to other key actors and individuals. It also became clear that the networks associated with these two GMEs would not be discrete; they would cross-cut each other. Therefore, whilst this part of the fieldwork was not interested in undertaking a comparative study, some of the differences between the two cases are highlighted in the empirical chapters. Fundamentally, though, the tracing of the networks of two GMEs was determined solely on methodological grounds.

Starting with the two research managers who were responsible for initiating the innovation of the two GMEs, interviews were conducted about the specific nature of the innovation. Two sets of questions were seen as especially important. The first related to the practices of what this innovation involved while the second focused on the networks and the other individuals associated with the innovation. A third set of issues examined developments in agro-food biotechnology. From these initial contacts, interviews were arranged with the other individuals involved in the innovation process. Through this 'snowball effect' it was hoped that key individuals and organisations throughout the innovation milieu would be identified and interviewed. Despite the potential enormity of investigating the networks associated with these GMEs, the research was aided by two factors. To begin with (as demonstrated during the pilot study), it was relatively easy to arrange interviews on site, especially when interviewees were asked to facilitate the process.[20] Secondly, although there were problems of drawing boundaries in terms of who to interview, it became apparent that on a day-to-day basis the number of individuals and organisations people dealt with were relatively small.

As with the pilot study, interview schedules were employed, although unlike the pilot interviews the list of questions was not entirely fixed as individuals were encouraged to talk freely about biotechnological innovation (see **Appendix C**).[21] To make the fieldwork easier to organise and manage, the interviews were divided up into four interconnected series. This process was less influenced by

[20] In many cases, help entailed getting the interviewee to arrange the interview for me. In fact, a number of my 'elite' interviewees arranged meetings during interviews. This saved considerable time and effort (one interview in Denmark took over twenty calls to arrange). But having interviews arranged for you was not always a good idea. For example, one interviewee 'encouraged' to talk to me, clearly resented this and was not especially helpful.
[21] The order of questions often differed in different interviews and depended on the responses of the interviewees; that is, the interviewing was an iterative process. That said, in broad terms most of the themes and issues were covered in each case.

theoretical elements and more by practical concerns. The first series of interviews involved individuals and organisations directly involved in the innovation of the GMEs in Denmark and the Netherlands, such as R&D managers and scientists, technicians, legal representatives, marketing and sales managers, product specialists, and production managers. The second series of interviews centred on individuals 'indirectly' involved in (bio)technological innovation in Denmark and the Netherlands, and included civil servants, parliamentarians, ministerial officials, regulators, research foundation directors, and trade and consumer lobbyists. The third series of interviews dealt with inter/supra-national levels and involved interviews with key individuals in international organisations indirectly involved in all aspects - from regulation to financing - of innovation in GMEs. Organisations included the following: Commission of the European Communities (CEC), European Parliament (EP), Food and Agricultural Organization (FAO), Organization for Economic Co-operation and Development (OECD), United Nations Education, Science and Culture Organization (UNESCO), United Nations Environment Programme (UNEP), and the World Trade Organization (WTO).[22] The final series of interviews focused on when the GMEs entered the UK and included individuals and organisations involved in the regulation, retailing, marketing and consumption of the GMEs in the UK.[23] The interviews were semi-structured and sought to gain answers and insights into the two main questions underpinning this research used to examine the main characteristics of innovation in (agro-food) biotechnology: 'what' and 'how' were the GMEs specifically and agro-food biotechnology generally, being developed and applied. 100 interviews across 7 countries (Belgium, Denmark, France, Italy, Netherlands, Switzerland and UK) were conducted between September 1996 and June 1997 and are listed in **Appendix D**.

Quite apart from the practical aspects involved in organising and undertaking interviews, several other issues emerged. For Law (1994), for instance, as part of undertaking a 'modest sociology', how to conduct interviews, how interviews are recorded and analysed, and ultimately the negotiation of the

[22] Fortunately, most of these organisations were based either in Brussels, Geneva, Paris or Rome.

[23] In the end, because of the constraints of time and resources, final consumers were not interviewed. The networks were followed as far as food retailers in the UK.

position between the researcher and the researched, need to be taken into account. For this research three issues need to be highlighted. First, getting interviewees to talk (in)formally and informatively was clearly a critical issue when undertaking this part of the fieldwork. Leaving aside some of the specific considerations when conducting 'elite interviews' (for which, see McDowell, 1991; McDowell and Court, 1994; Schoenberger, 1991, 1992), it was recognised that whilst the GMEs were being followed, the interview schedules needed to be tailored. For example, not all interviewees were questioned intensively on the 'technological' aspects of agro-food biotechnology; in some cases it was seen as more useful to consider their sources of information on agro-food biotechnology. Interviewing was seen as a recursive process and as themes emerged from one interview they were developed and used in subsequent ones.[24] This process ensured the continuity and logic of the interviews, as well as making them more relevant and sensitive to the particularities of the research.[25]

Second, given the 'international' nature of the research some 'cultural' factors had to be considered. For example, most of the interviews were conducted in English,[26] which for some non-native speakers may be considered disadvantageous; in practice, the overall competence in English was surprisingly good, with interviewees relishing the prospect of 'practising' their English. This is not to say that language was not a critical aspect in negotiating relations with the interviewees. But in terms of gathering the necessary information it appears to have had a limited impact.[27] Adjunct to the use of English was the issue of learning the language of the 'trade'. In an obvious sense some understanding of the basic

---

[24] The recursivity of the interviews led to some interesting repercussions. For example, one of the themes that was raised early on in an interview in the Netherlands was a statement allegedly made by the Director of the Science Foundation about the need for universities and the public sector to do more 'applied' research. This was hugely controversial and was an interesting way of introducing interviewees to the relationship between private and public sector research. In one interview with a parliamentarian, it transpired that they had a meeting with the Director directly after me, and she assured me that she would raise this issue during the meeting!

[25] This 'reflexive' approach to the interview series raises questions about 'replicability'. Despite the flexible nature of the interviews comparisons amongst responses were generally possible.

[26] Some of the interviews were conducted in Dutch and French and were translated during transcribing.

[27] For the record, I would like to point out that the interview extracts that follow have not been corrected for errors of grammar and/or syntax which may have been made by interviewees whose first language was not English.

processes involved in (agro-food) biotechnology was required for this study. This was not only restricted to the 'scientific' and 'technological' matters. It was necessary to have, for instance, some appreciation of some of the issues that confronted business generally and the biotechnology sector specifically.[28]

Finally, there was the issue of how to analyse the interviews. All but four of the interviews were recorded and fully transcribed.[29] There are a number of computer-aided qualitative data analysis software (CAQDAS) programmes for interview material (Cook and Crang, 1995; Weitzman and Miles, 1995). Leaving aside an in-depth critical evaluation of these systems (for which, see Crang et al., 1997; Hinchliffe et al., 1997), they were not used in the analysis because they were felt to make invisible the reasoning behind the coding and categorising (Crang et al., 1997:774). Instead, the hard copy of the transcripts was employed. An open coding system was adopted in which the main events, themes and categories were manually applied to the interview transcripts. Although time-consuming, this method allows greater familiarity with the transcripts, and further themes and ideas to be identified. Broadly, the codes corresponded to the particular question that was being addressed - 'what' and 'how'. These were sub-divided into particular themes. Some of the codes used for the first category included views on definitions of biotechnology, current developments in agro-food biotechnology, the multi-/inter-disciplinary nature of agro-food biotechnology, and whether biotechnology could be considered as natural. In the second 'how' category some of the codes covered 'hard' categories such as aspects of the R&D process, production, marketing and sales, regulation, the funding of biotechnology, and public-private co-operation. The third category of codes covered slightly more abstract concepts such as the emergence of technoscience, the nature of organisational geographies, the essence of science and technology, and the nature and production of knowledge associated with biotechnology. Fundamentally, these three sets of codes were connected within the framework of the broader categories and written up into the three empirical/analytical chapters (**Chapters 5-7**) of the thesis.

---

[28] This expertise was gained by following an undergraduate course in biochemical engineering and biotechnology at UCL and keeping up-to-date with the many trade journals, such as *Nature biotechnology* and *Trends in Biotechnology*.

[29] No pattern for the refusals for recording are identifiable. Suffice to say, the worry about being misquoted and the possible sensitivity of the material may have played a part.

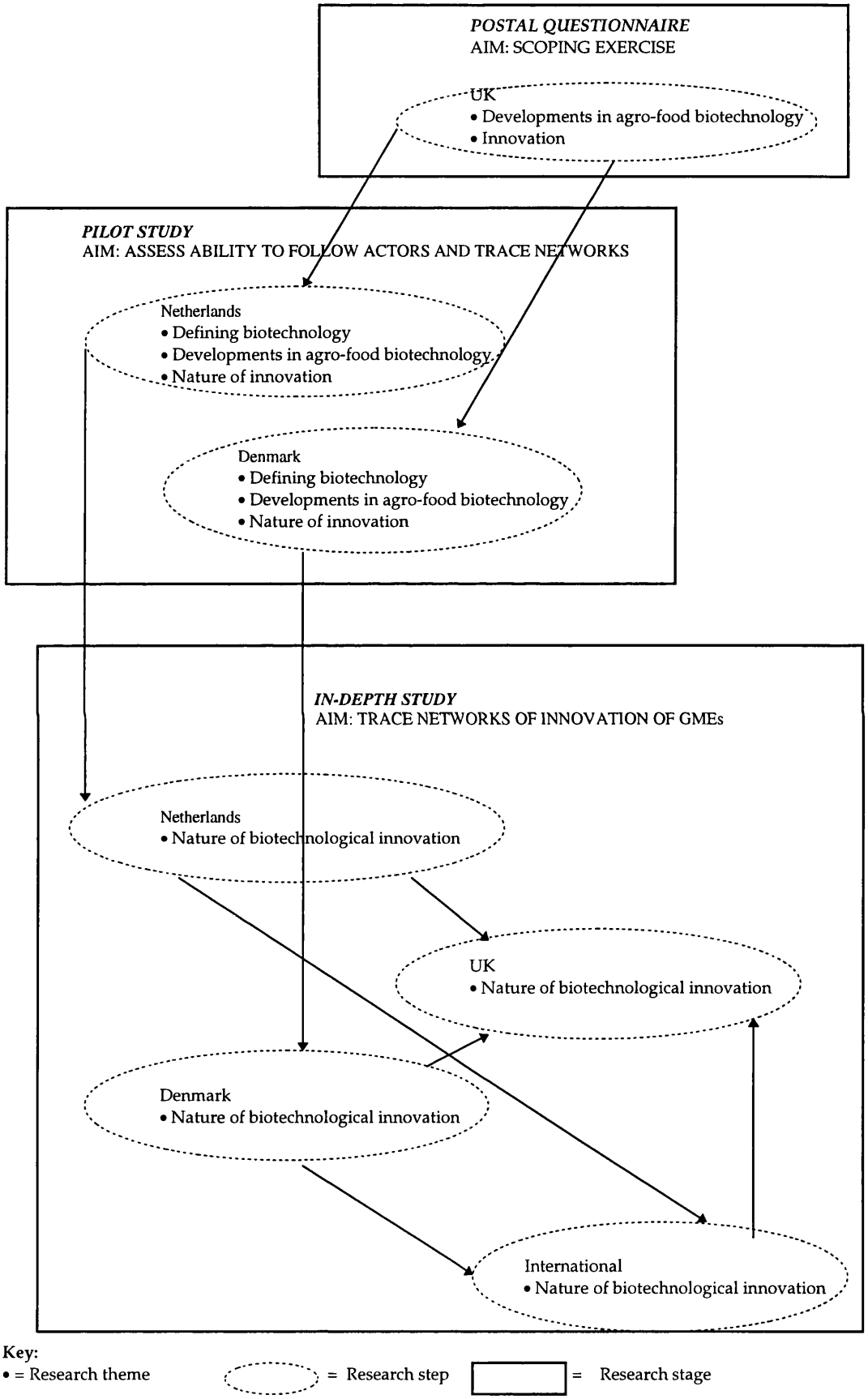
Taking all the aspects of the research techniques used in this study together, it is important to note that no claim for universal representation is made. For the most part, the research method developed in dialogue with the theoretical insights and research questions. Nonetheless, the details of the research techniques employed can be seen to have wider methodological (and theoretical) relevance for other studies on innovation (see **Chapter 8**). Moreover, given the wealth of information gathered in this research project, it is not surprising that the presentation of data is rather selective. Finally, the research techniques outlined above owe much to trial and error given their recursive nature, including the writing up of the research. That noted, there is some logic to the way the research techniques are connected to each other as shown in **Figure 4.1**. Nevertheless, it is important to assert that the 'account of network building may often have to be gained retrospectively' (Murdoch, 1994:22). Therefore, the three empirical chapters which follow are as much to do with research techniques discussed in this chapter as with the analytical framework developed in **Chapter 2**.

4.5 Summary

The principal aim of this chapter is to provide an overview of the research techniques employed. Avoiding the sharp categorisation between quantitative and qualitative methods, both surveying and interviewing techniques were employed. The surveying aspect of the study, conducted in the UK, was used to analyse some of the broad concepts related to innovation in agro-food biotechnology. Of particular concern was the need to establish the pattern of development, and the nature and types of relationships that this accompanied. Focusing on the particular case of innovation in GMEs, the main research techniques centred on an interview-based approach. Despite methodological and theoretical problems with ANT, the notion of 'following' the actors was adopted to trace the network(s) of biotechnological innovation. More pointedly, GMEs were used as a research tool to identify the network. Following a pilot study, which helped concentrate the analysis onto two GMEs and highlighted the importance of focusing on the networks, the remaining part of the chapter outlines how the interview-based

approach was put into practice. The next three chapters present the empirical findings from the research.

Figure 4.1: Summary of research design



Key:
• = Research theme = Research step = Research stage

5

WHAT 'IS' AGRO-FOOD BIOTECHNOLOGY?: ACTUAL DEVELOPMENTS IN A CONTESTED TERRAIN

5.1 Introduction

In this first empirical chapter, the research question 'what are the main developments in agro-food biotechnology?' is addressed. Agro-food biotechnology faces an uncertain future. In technological terms the future of agro-food biotechnology appears bright, but this may not easily translate into economic viability. To take a recent example, despite demands by consumer organisations for the separation and clear labelling of GM products,[1] both Monsanto's GM soya and products containing it have now entered Europe unlabelled (*Independent* 1996a; *Le Soir*, 1996; *Guardian*, 1997a). Recently, this use of GM food has been challenged in the UK with the announcement of the banning of such products by some food retailers (*Independent*, 1998c). But whilst Monsanto's GM soya highlights some important debates concerning (agro-food) biotechnology - what its development and application means for consumers, for instance - one issue that remains poorly understood is precisely what areas is agro-food biotechnology *actually* being developed and applied?

The analytical framework developed in **Chapter 2** proposes that biotechnological innovation needs to be conceptualised in terms of a network. This framework is seemingly developed for the research question 'how does innovation in (agro-food) biotechnology take place?', the subject of the next chapter. But in highlighting the multi-dimensional character of biotechnological innovation, the framework also allows the question 'what is agro-food biotechnology?' to be examined. Two different kinds of discussion are constructed in this chapter. In 'pragmatic' terms, the material in **Section 5.2** identifies and describes some of the

[1] According to the American Soybean Association (ASA) it is impossible to separate GM soya from others. In response, retailers such as Sainsbury's have put together product guides of foods free from GM soya. Furthermore, some retailers, such as Iceland, have banned the use of GM soya in their food altogether.

developments in agro-food biotechnology. Using a 'system orientated approach' this section is divided up according to the five main areas of agro-food biotechnology (raw materials; ingredients, production and processing aids; food material; waste material; and environment) identified in **Chapter 3**. It contains concrete results on both developments taking place, and the likely development trajectories they may follow. **Section 5.3** takes a step back from these observations and looks at how key individuals involved in biotechnological innovation conceptualise biotechnology. In a broad sense, this section is more 'ontological' as a more precise analysis of what 'is' (agro-food) biotechnology? is given. In **Section 5.4**, some links between the 'pragmatic' and 'ontological' aspects of (agro-food) biotechnology are drawn out.

5.2 Actual developments in agro-food biotechnology

This part of the chapter rests on information gathered from both the surveying and interviewing aspects of the study design (see **Chapter 4**).[2] Before describing the results, a few specific points need to be made. First, the system orientated approach used to organise the survey is subdivided into more specific activities such as production, modification and preservation, and identification (see **Figure 5.1**; also see Question 5, Section 2 of Questionnaire in **Appendix B**). Second, the results from all the subdivisions are grouped into the five main categories of the food provision 'chain' and are shown in **Tables 5.1-5.5**. When examining the tables two aspects of the information need to be borne in mind: first, the percentage figures shown in the tables correspond to the total number of responses (855) rather than number of respondents (45) as answers were requested for each subdivision of agro-food biotechnology; and second, the small size of the sample of respondents does not allow reliable statistical analyses to be undertaken even if it does provide the opportunity to make some general observations about actual developments in agro-food biotechnology. Third, despite the broad spectrum of techniques and technologies associated with biotechnology, it focuses primarily on rDNA technology as it is considered likely to have the greatest impact on agro-food systems (see **Section 3.2**). Fourth, respondents are asked to think about the

[2] I have presented and discussed some aspects of this information elsewhere (see Ahson 1997).

commercial availability of agro-food biotechnology over three time periods: currently, two years and five years (of course, the commercial availability of such technologies did not imply they were currently employed in the provision of food as use, ultimately, depends on negotiations between industrial, government and public interests).[3] Fifth, at interviews, interviewees were asked to respond to the question, 'what are and will be the major developments in agro-food biotechnology?' (see interview schedules in **Appendices B** and **C**) The results of the investigations are presented below.

Figure 5.1: System orientated approach for biotechnology

Raw material
Production (in-vitro fertilisation, solid-state fermentation) *
Modification/improvement (bioconversion of polysaccharides)
Preservation (silage, coffee fermentation)
Identification/quality assessment (microbial methods)

Ingredients, production and processing aids
Production (enzymes, vitamins, vanilla)
Modification/improvement (hydrolysis of proteins)
Preservation (immobilisation of biocatalysts)
Identification/quality assessment (enzymatic and microbial methods)

Food material
Production (bread)
Modification (meat tenderisation)
Preservation (lactic acid fermentation)
Processing methods (enzymatic separation, fermentation)
Identification/quality assessment (microbial and biological methods, biosensors)

Waste material
Improvement/modification (single-cell protein, vinegar)
Utilisation (protein recovery)
Identification/quality assessment (enzymatic and microbial methods)

Environment
Improvement/modification (air/water purification)
Preservation (soil preservation)
Identification/quality assessment (biosensors)

* Examples in parentheses

Source: Knorr (1987:97)

[3] It is important to note that 'currently' here refers to early 1996 (see **Sections 4.3 and 5.2.6**).

5.2.1 Raw material

The potential use of rDNA technology in the production of raw material in agro-food systems could be enormous (see **Section 3.3.1**). Starting with the survey (see **Table 5.1**), a large section of the respondents, 42 percent, across all organisations say that rDNA technology is currently commercially available for the production of raw materials; a further 34 percent of respondents feel that rDNA technology will be commercially available in the next five years. This enormous potential is reinforced by the interviewees as a quarter of them mentioned developments in this area as being significant for the development of agro-food biotechnology. For example, one research manager is of the following opinion:

> "I think that the genetic engineering of plants is something which is already coming into effect. In fact, it is not a potential development but one that is already taking place....I think that will be the major change in the whole area (agro-food biotechnology)." BS, Head of Biotechnology, Multinational Chemical Company, The Netherlands (my translation)

But whilst there appears to be a shared optimism about the use of rDNA technology for the development of plants for raw material production, the survey masks a hesitancy to anticipate developments in the animal sector. According to one research scientist:

> "Well of course people will use molecular biology to make all kinds of material, I mean bioplants, probably not by animals although this is fashionable. I don't think the general public will accept animals....I don't know whether you followed the discussion here in Holland about this transgenic cow (bull) Hermann? There was a lot of discussion about it because it was producing lactoferon. And they said it was a very useful compound because it has an anti-bacterial element in it but this hasn't been proven." RW, Research Scientist, University, The Netherlands

Leaving aside the specific issue of the transgenic bull, typically when it came to developments in the animal sector, a distinction is made between uses for food consumption and those in the medical fields. Many interviewees suggest that people are more likely to accept the use of rDNA technology on animals for medical purposes (see **Section 1.2**).

These discrepancies are also reflected in recent developments in the UK. Despite concerns with the emergence of resistance to *Bt* transgenic plants (Kleiner, 1997; Roush

and Shelton, 1997), as noted earlier Monsanto's GM Roundup Ready soybean now enters the UK (*Independent* 1996a; *Guardian* 1997a). Similarly, although the EP on 8 April 1997 censured an earlier CEC authorisation for Ciba-Geigy's (now Novartis) *Bt* maize to enter Europe, subject to further examination by scientific committees (*The Splice of Life*, 1997a), and the more recent threat of barriers for recombinant maize products entering the EU (Fox, 1998; Hodgson, 1998), *Bt* maize is set to enter the UK by the end of 1998 (FDF, 1998). By contrast, the use of the GM gene Bovine Somatotropin (rBST) is banned in Europe until 1999 (Price, 1995; Grace, 1997:104). This decision is based on two considerations: the introduction of rBST is not in line with the reform of the CAP as it would negatively affect dairy and beef markets; and there is a strong aversion to the use of rBST amongst consumers (Bijman, 1995). Finally, despite successes with the cloning of sheep (Gordon, 1997) and cows (Pendick, 1997a), there is a greater degree of reluctance in the UK to accept the use of rDNA technology for animals rather than plants (FDF, 1996b; CEC, 1997a; *Guardian*, 1997c). Some commentators believe that transgenic fish are likely to be the first marketable transgenic animals for human consumption (Hew and Fletcher, 1997).

Table 5.1: Aggregate data for raw material

No. Respondents	Currently	In 2 years	In 5 years	Don't know
Total (n=45)	42%	15%	19%	23%
Universities (n=10)	50%	13%	25%	12%
Commercial (n=14)	34%	15%	22%	29%
Agriculture (n=3)	42%		33%	25%
Manufacturers (n=8)	41%	21%	17%	20%
Retailers (n=5)	33%	17%		50%
Government (n=3)	50%	17%	8%	25%
Others (n=2)	50%	50%		

5.2.2 Ingredients, production and processing aids

It is often suggested that the area of ingredients, production and processing aids will experience some of the greatest changes brought about by rDNA technology (see **Section 3.3.2**). Over half the respondents say that rDNA technology is currently commercially available for use in this area (see **Table 5.2**); a further quarter of the respondents say that they will become available in the next five years. Given the range of activities involved in this area of biotechnology, a detailed assessment of developments in this sector proves difficult. Nevertheless, the importance of rDNA

technology to the manufacturer of enzymes is widely cited (just over 34 percent) as an important growth area.[4] As one interviewee remarks:

> "Well, if we just look at what you can find in supermarkets at the moment now, for example in your laundry powder, all the enzymes that are in are now recombinant, nobody knows that but they are recombinant. You will see that in the next few years a lot of the enzymes which are used for processing food will all become recombinant. And since a lot of new enzymes will come, you might gradually see a change from chemical substitutes or chemical food processing aids to biological food processing aids. Again something you might not see or taste but which...actually is a real change...I think the future will definitely be recombinant but it is difficult for me to predict whether the future will start next year or whether it takes ten years before we lose our fear of this technology." MO, Head of Gene Technology, Research Institute, The Netherlands

Despite the interviewee's reluctance to specify the time-scale for the commercialisation of GMEs, in the UK they already play a significant role in the provision of food. For instance, GM chymosin derived from a GM *Kluyveromyces lactis* source was cleared by the UK Government for use in cheese making as early as 1991 (ACNFP, 1991:3).[5] Of the many enzymes used in food and drink production, recombinant rennet or chymosin, used for the coagulation of milk in cheese making, is one of the most advanced. The traditional source of chymosin has been calf stomach, but the number of calf stomachs has been decreasing and chymosin substitutes have had to be found. Using rDNA technology, the main gene responsible for the coagulation of milk can be expressed in a host of growth organisms. GMEs are also making an enormous impact upon the animal feed industry, estimated in Europe and the US to be worth £25 billion per annum (DTI, 1996a:7). Here, as with the general food grade area, GMEs are beginning to replace conventionally produced enzymes (OECD, 1992:69). In the UK poultry industry, for instance, GMEs are being used to improve the digestibility of animal feed to increase feed efficiency and, therefore, allow cheaper raw materials to be used (DTI, 1996a:6).[6] A further development in Ireland, and currently

---

[4] Developments in food grade GMEs have to be set within the context of broader developments in enzymology. A number of interviewees point out that the largest growth sector for GMEs is in non-food applications such as detergents.

[5] Other GMEs which have been given permission for use in the UK are chymosin from a GM *Escherichia coli* (ACNFP, 1991) and GM bakers yeast from *Saccharomyces cerevisiae* (ACNFP, 1990). Importantly, until regulations came into effect at a European level, in the UK the regulatory system of approval for enzymes, and notably GMEs, was a voluntary one (Hammond, 1994; AMFEP, 1995a; Praaning, 1996). This issue is discussed further in **Section 6.3.4.**

[6] As a side issue, according to one research manager of enzymology in the Netherlands, the use of rDNA technology in the animal feed sector is a useful marketing tool. He suggests that in some countries, such as Thailand, GMEs are considered 'sophisticated' and therefore

under consideration by UK food retailers, involves sensitive genetic testing. In Ireland, consumers at SuperValu stores are given the opportunity to buy beef which has been BSE tested. The BSE test, marketed by an Irish company Enfer Scientific and licensed from Proteus International based in Macclesfield in the UK, is based around tissue from slaughtered animals being treated with GMEs which digest normal proteins but become attached to rogue prions associated with BSE (Spinney, 1998). Similarly, following the entry of GM soya and GM maize into the UK, supermarkets may start employing DNA tests, developed by the recently privatised Laboratory of the Government Chemist, to identify characteristic DNA sequences that flank the genes introduced into a range of GM crops (Motluk, 1998).

Table 5.2: Aggregate data for ingredients, production and processing aids

No. Respondents	Currently	In 2 years	In 5 years	Don't know
Total (n=45)	52%	14%	10%	24%
Universities (n=10)	53%	20%	8%	20%
Commercial (n=14)	60%	8%	8%	26%
Agriculture (n=3)	42%		33%	25%
Manufacturers (n=8)	61%	7%	14%	18%
Retailers (n=5)	50%	25%		25%
Government (n=3)	33%		8%	58%
Others (n=2)		100%		

5.2.3 Food material

The area of food material is frequently cited as an important sector for developments in agro-food biotechnology (see **Section 3.3.3**). However, only a third of respondents believe that rDNA technology is currently commercially available for the production of food material; by the end of five years, 75 percent of respondents feel that rDNA technology would be so employed (see **Table 5.3**). Only a few interviewees (under 4 percent) expressed any enthusiasm for developments in this area, but two developments appear to be experiencing some growth. The first involves functional foods such as:

> "...the use of bacteria to inoculate food...beneficial bacteria, like now you can buy some milk products with some bacteria that are good for your health. But I think you will maybe see a number of other things...maybe combating salmonella, and things like that.

'better'. That said, this person still feels that price is one of the most important factors influencing sales in the enzyme market.

You can use other bacteria to inoculate meat or something like that." TM, Research Scientist, National Research Institute, Denmark

The second development covers convenience food. As one interviewee describes:

"...you have a powder and you put water into it and then you get potatoes and things like that....Bread which you have to finish yourself, just like mimicking the last part of the baking process." RB, Research Scientist, Firm C,[7] The Netherlands

Given the limited interest expressed in this area, it is unsurprising that it is hard to identify any products in the UK which have entered the market employing these techniques. More generally, in Europe there is a considerable amount of work developing functional dairy products with bioactive ingredients, particularly yoghurt (Hasler, 1998). Examples include, Nestle's LC1 fermented milk product (Switzerland); Fysiq yoghurt from Mona (The Netherlands); and Actimel Cholesterol Control from Danone (Belgium) (ibid.:87).[8] Nevertheless, in the near future, it is prudent to suggest that the use of agro-food biotechnology in the production of food material appears to be limited. Advances that are taking place tend to focus on speciality areas such as functional foods (an area which ironically incorporates the more acceptable health/medical biotechnology with developments in food provision). A good example of such developments is provided by the Campbell Soup Company in the US which is using rDNA technology to produce foods lower in saturated fats (ibid.).

Table 5.3: Aggregate data for food material

No. Respondents	Currently	In 2 years	In 5 years	Don't know
Total (n=45)	35%	20%	20%	26%
Universities (n=10)	22%	27%	29%	22%
Commercial (n=14)	31%	25%	20%	23%
Agriculture (n=3)	33%		7%	60%
Manufacturers (n=8)	51%	14%	14%	20%
Retailers (n=5)	45%	20%	20%	15%
Government (n=3)	40%		13%	47%
Others (n=2)	20%	60%	20%	

[7] A description of Firms, A, B, C and D is given in **Sections 4.4.1** and **6.3**.
[8] In the UK there has been an interest in biotechnological products more generally. For instance, in the *Guardian* (1996b) an advertising campaign was underway for Yakult, a Japanese fermented milk drink containing a lactic acid bacteria which is said to help digestion. Whilst it is unclear whether rDNA technology is used in its production, it does reflect the growing interest in biological foods.

5.2.4 Waste material

The area of waste material has received little attention in the literature (see **Section 3.3.4**), and respondents across all organisations give it a rather low rating (25 percent) for current commercial availability (see **Table 5.4**), a figure rising to 40 percent over the next five years. A sizeable minority, 35 percent, are unable to offer an estimate for commercialisation in this area,[9] a lack of enthusiasm also reflected in the interviews where less than 4 percent of interviewees mention it. One of the few projects which is identified aims to:

> "...improve the utilisation of raw materials....[This] gives a higher yield and better utilisation....[and] also has a major impact because you get a reduction in the waste stream...." JN, Research Scientist and Director of Biotechnology Trade Organisation, University, Denmark

Despite this lack of attention, in the UK there are a number of key developments in the use of rDNA technology for waste material. One of the most important involves the cleaning of food industry waste by GMEs (DTI, 1995a; Grasius et al., 1997). This waste often contains suspended organic solids and fats that can foul surfaces and block drains, and GMEs are being manufactured for use in surface cleaning. For instance, anaerobic digestion, is used by Coca Cola Schweppes Beverages at its factory in Wakefield (UK), now the largest soft drinks complex in Europe (DTI, 1995a). Anaerobic digestion processes involve a system by which oxygen is excluded and where the organic compounds are metabolised to yield biomass plus a gaseous mixture (biogas) containing methane and carbon dioxide. The process achieves a large reduction in the biochemical oxygen demand of high strength waste and has the advantage of producing relatively low amounts of sludge. Interestingly, work is now being conducted whereby these enzymes are directly put on to the surface of the waste to tackle decontaminated polluted waste water from agro-food industries (Coghlan, 1997). A different development involves the conversion of waste into saleable products. Despite adjunct worries to do with BSE, the prospects for recycling slaughterhouse waste and the by-products of fermentation are growing (Kherrati et al., 1998). For example, Ulster Farm By Products in Northern Ireland is using a freeze dried cocktail of bacteria in a sewage plant digester to breakdown

[9] The rather poor response rate may reflect the sample profile of respondents (see **Table 4.1**).

wastewater from pork and bovine tissue (DTI, 1996a). The liquids and solids produced as a by-product of the digestion are sold as fertilisers, while the biogas produces sufficient energy to run the digester and heat the hot water needed in the abattoir (Kendall et al., 1997).

Table 5.4: Aggregate data for waste material

No. Respondents	Currently	In 2 years	In 5 years	Don't know
Total (n=45)	25%	21%	19%	35%
Universities (n=10)	25%	39%	18%	18%
Commercial (n=14)	13%	17%	33%	37%
Agriculture (n=3)	33%		33%	33%
Manufacturers (n=8)	48%	14%	5%	33%
Retailers (n=5)	22%	11%		67%
Government (n=3)	11%	11%	11%	67%
Others (n=2)		67%	33%	

5.2.5 Environment

Given growing concern with the environment, the inclusion of this area as a separate category in the food provision chain is important (see **Section 3.3.5**). As can be seen in **Table 5.5**, there is a low expectation across all the organisations on the current availability of rDNA technology; a further 37 percent of respondents believe, however, that commercialisation could occur in the next five years. As with the waste material category, a sizeable minority, 43 percent, cannot offer any estimation of the commercialisation of biotechnology in the area of the environment.[10] Whilst this low response rate may reflect the sample distribution of the survey, a slightly more optimistic picture about developments in this area emerges from the interviews; about 13 percent of interviewees mention the importance of rDNA technology for the environment. One important area centres on problems associated with agro-food systems brought about by earlier attempts at improving agricultural productivity. As one interviewee describes:

> "I think that when we are going to look at and go into biotechnology then it is to solve some environmental problems. It is not to boost production and so on, it is more to solve some of the...environmental problems of agriculture. And maybe it is one of the objectives to reduce pesticides, and genetically modified plants could be very interesting here. But of course we are very aware of the dangers in these processes and therefore to

[10] Once again the profile of respondents and interviewees may reflect this rather low response rate.

minimise the dangers, better knowledge is necessary." SB, Head of Research, Ministry of Agriculture and Fisheries, Denmark

From the information provided above it is difficult to present an accurate picture of developments in agro-food biotechnology for use in the environment; although recognised as an important area generally, developments are arriving slowly. Nevertheless in recent years there have been some interesting developments in this area in the UK which suggest a more encouraging view. For example, Anglian Water and Ipswich Borough Council have developed composting technologies to create an environmentally beneficial method of recycling industrial organic waste material (DTI, 1997). This method involves composting sewage sludge with biodegradable components of the refuse collected by the Council using a tunnel composting system. These techniques are also being developed for the biodegradation of a number of toxic pesticides, herbicides and biocides which are widely used in agriculture and industry; for example, at a research level, the complete microbial degradation of the toxic insecticide parathion has been achieved in a mixed community of microbes (DTI, 1995a). There are many practical problems with these research developments and it is prudent to assert that despite environmental impetus, the 'greening' of industry through biotechnology is at a very early stage (Tils and Sørup, 1997).

Table 5.5: Aggregate data for environment

No. Respondents	Currently	In 2 years	In 5 years	Don't know
Total (n=45)	20%	14%	23%	43%
Universities (n=10)	21%	14%	39%	25%
Commercial (n=14)	15%	15%	30%	39%
Agriculture (n=3)	33%			67%
Manufacturers (n=8)	29%	10%		62%
Retailers (n=5)	22%			78%
Government (n=3)		33%	44%	22%
Others (n=2)		67%	33%	

5.2.6 Some reflections on actual developments in agro-food biotechnology

This first part of the chapter seeks to present information on actual developments taking place in agro-food biotechnology. It is important to recognise that the survey was conducted more than 2 years ago. Nonetheless, it is still possible to draw some instructive conclusions. There are five points to note here. First, most of the major developments in agro-food biotechnology to date involve the improvement,

development and production of food processing aids rather than food products, and it is in the area of raw material production, especially in agriculture, that will experience the most dramatic changes, and indeed profits, in the near future. From the examples cited above, it is clear that cheese produced using GM chymosin and tomato purée from GM tomatoes, provide ready illustration of how biotechnology can impact upon food provision. But as one biotechnology manager notes:

> "...there are certain advantages with GM foods....But the money is to be made in bulk commodities not in tomato purée." GB, Biotechnology Manager, Food Retailer, UK

Second, considerable technological limitations remain with biotechnology:

> "[T]here is a danger that we are too optimistic as the technology still needs to be developed." ME, Research Director, Firm D, The Netherlands (my translation)

The technology that produced Dolly the lamb, the first successfully cloned mammal from the cells of an adult, is seen to be far from perfect; in fact Dolly was the only success out of 277 implanted embryos (Gordon, 1997). There are real doubts over whether these techniques can be used to mass-produce clones (*Economist*, 1997b; Pendick, 1997a). This is not to say that mass-produced cloning will not be attempted (Cohen, 1998), but apart from the associated moral and ethical problems, it is unlikely to be achieved in the near future.

Third, the forthcoming biotechnology 'revolution' touted by many commentators needs to be qualified considerably. In an interview extract worth quoting at some length one interviewee highlights some of the problems with biotechnology:

> "In principle...it (biotechnology) has enormous potential. But I think in 10-15 years when we look at the constructs we are using now we will think they were childish...Until now in plant biotechnology we have only used single genes, and with single genes you can only do tiny things. But if you take more complex gene constructs you can address more complex questions and get things that work in more complex situations....Which means that the claims made ten years ago, that this would cause a revolution in plant breeding, that is probably true when we look at it from fifty years from now, but people thought that the revolution would be here within five years and that is not really feasible. People weren't aware...claims were made by molecular biologists who didn't know about plant breeding and didn't know about industrial planning....It has always been advertised as a precise technique and you know exactly what you are doing and it is not that at all, especially not in plants....In plants the genes that you put in still now just go anywhere. They go to the wrong position usually because of the law of averages. So then you have to make a lot of plants and then get out the ones that really do what you like them to do,

so it goes a lot slower...." HB, Secretary, Advisory Committee on Genetic Modification, Ministry of Environment, The Netherlands

This interviewee suggests that there is a great deal of naiveté amongst both the people that use and apply biotechnology, and also those that develop it.

Fourth, whilst it is difficult to make concrete predictive statements given that developmental trajectories are in such a state of flux, two general developments are worth highlighting. The first is the general consensus that radical developments brought about by biotechnology are more likely to be socially acceptable in the medical-pharmaceutical area (Hallman, 1996; FDF, 1996b; CEC, 1997a). Developments in agro-food biotechnology which have obvious health benefits (such as functional foods, or low fat oils) may benefit from this tendency. Secondly, although much of the discussion above is centred around rDNA technology, biotechnology entails a range of fragmentary techniques and technologies. Thus whilst there appears to be a shared ability to engineer genes in a targeted fashion (see, for example, Callan, 1996), it remains the case that many of the developments outlined above have very different research potential. To take a simple example, whilst genes have been expressed relatively easily in host organisms used in the production of GMEs, it does not necessarily mean that in 'higher' organisms, such as animals, rDNA technology will be successful.

Fifth, and finally, in the course of identifying and discussing some of the main developments, it is easy to forget that there are still major differences of opinion. On a superficial level, the area of raw material from the survey data shows a considerable divergence between agents on how they viewed developments in this area; for example, 50 percent of respondents from universities suggest that rDNA technology is commercially available compared to a figure of 33 percent for respondents working in the retailing sector.[11] Similarly, in the area of food material, it is interesting to note that agents involved in applying biotechnology such as retailers and food manufacturers appear more optimistic about the commercialisation of rDNA technology than those agents involved in developing it.

[11] Admittedly this observation is made from a very small sample. Nonetheless, there are noticeable differences throughout the empirical findings.

Behind all these points is a fundamental issue of how biotechnology is conceptualised. Although it is difficult to make definitive statements about differences in opinion, as evoked in the last point there is some debate about what biotechnology entails. Whilst in recent years a considerable amount of research has been undertaken looking at the attitudes and concerns of the public towards biotechnology, apart from a few general examples, the opinions of those involved in innovation and R&D are surprisingly neglected. The next part of this chapter analyses the meaning and significance of (agro-food) biotechnology to them. [12]

5.3 Biotechnology in a contested terrain

Providing a definition of biotechnology at first seems unproblematic. In **Section 1.1**, biotechnology is defined as 'the application of biological organisms, systems, and processes based on scientific and engineering principles, to the production of goods and services' (OECD, 1992:29). Another popular definition of biotechnology in the literature comes from the EFB (1995) and is 'the integration of natural sciences and engineering sciences in order to achieve the application of organisms, cells, and molecular analogues for products and services' (see **Section 3.1**). Quite clearly, these two definitions share much common ground: there is a notable emphasis on the biological aspects of biotechnology and how they entail the integration of a number of disciplines and areas of knowledge. And given the importance of the OECD and EFB it is perhaps not surprising that these definitions are widely used in the literature. And yet for all their simplicity, and indeed attractiveness, these definitions assume some sort of consensus on what biotechnology involves. But the field research fails to identify any widespread consensus. Over 43 percent of interviewees had difficulty defining biotechnology. A typical response is as follows:

> "I've never really been thinking about that to be honest....It is hard to define [Why?] Because ...biotechnology...is you know...it is more a phenomenon for me, it is more an area...Biotechnology is also a mystery in that, you do not know everything and that is maybe where culture comes in....I'm trying to think as I talk...because biotechnology is maybe also there is something about history and also about...the possibility that genetic

[12] As with the first part of this chapter, I have presented and discussed aspects of this section elsewhere (see Ahson, 1998).

engineering...can improve existing biotechnology So...there are a lot of dimensions...." CB, Product and Marketing Manager, Firm A, Denmark

From this extract, there is a sense that the issue of what biotechnology involves is neglected by many of the individuals involved in its development. Here, 'biotechnology' appears to occupy different explanatory planes; that is, 'biotechnology' is used without 'knowing' precisely what it entails. This uncertainty with the term 'biotechnology' points to its multiple uses. This ambiguity, as discussed subsequently, has practical implications as many areas of social activity associated with biotechnology, such as regulation, require a degree of certainty over what 'biotechnology' entails.

A second important theme to emerge centres on the type of definitions of biotechnology. Despite problems with defining biotechnology, many definitions provided are rather broad in character:

"That is an interesting question because biotechnology is quite difficult to define, it is what we call an 'umbrella'...it is just simply an umbrella term. And what it (biotechnology) means is that we are now using biological knowledge and insights to make new processes and products. And that is the definition....There are all kinds of complex definitions, but most of them do not make much sense." RS, Professor of Biochemistry and Senior Government Advisor, The Netherlands

Apart from recognising the difficulty in defining biotechnology, the interviewee highlights the usefulness, and perhaps need, for a definition covering the broad range of techniques and technologies associated with the development and production of biological knowledge. In this sense, this interviewee provides the rationale behind the OECD and EFB definitions described earlier.

But unlike the view that an all-encompassing definition of biotechnology is beneficial, there is an equal sense that this can act as an hindrance. Another interviewee makes the following point:

"There isn't a good definition of biotechnology and sometimes this is damaging certain aspects of biotechnology....Perhaps it would be useful to give different types of biotechnology different names. Because now biotechnology covers the making of cheese and wine, to making transgenic cows...[and] everything in-between is called biotechnology...bacteria, plants, animals. Even the production of industrial enzymes, and antibiotics is biotechnology...." HB, Professor of Biochemistry and Founder of DBF, The Netherlands (My translation)

For this interviewee, there is a fundamental problem with different and diffuse technologies and techniques being grouped together because of their biological (but not necessarily living) character. 'Biotechnology' thus appears to have emerged or evolved in a rather piecemeal and fragmentary manner. In turn, 'biotechnology' is seen as inaccurate and unhelpful:

> "...normally we never use the word biotechnology, because we don't think it is an appropriate name anymore...because biotechnology is so broad. There is a lot of biotechnology in micro-organisms, and we don't really want to be connected to that necessarily." MH, Research Scientist, University, The Netherlands

A different issue arises from discussions about how the term 'biotechnology' is used.[13] One person comments:

> "....I don't know what you have experienced here in Denmark but the University of Copenhagen is trying to establish itself as a centre of excellence for biotechnology. And they started by asking all their staff members if they were doing biotechnology. And since they asked in a way that people thought that if they said 'yes' there might be more money, I think 250 scientists said 'yes' they were doing biotechnology!" PL, Director, National Research Foundation, Denmark

Many interviewees feel that 'biotechnology' is a fashionable concept, one that is reflected in the intense academic, media and public interest in the subject, and linked to the need to raise funds. As with accusations made in other areas of science and technology, such as climate change, the setting up of significant research programmes focusing on biotechnology, such as the EU Fourth Framework, can be seen as part of a circle of funding and research which links public expectation to research.

The different uses of the term 'biotechnology' is also evidence of attempts to bring about consensus so that a stronger perception of the focus and purpose of the field can be promoted.[14] One research director remarks:

---

[13] A similar issue arose when talking about novel foods. Novel foods according to the Advisory Committee on Novel Foods and Processes (ACNFP, 1990:5) are 'foods or ingredients which have not hitherto been used for human consumption to a significant degree and/or which have been produced by extensively modified or entirely new food production processes.' Although at first this seems a relatively straightforward definition it is ambiguous. In fact, one interviewee, the head of regulatory affairs at the *Levnedsmiddelstyrelsen* (Danish Food Agency), went as far as to suggest that the definition of novel foods is not a scientific one but a political one.

[14] A director of research at a multinational fermentation company remarked that scientists were 'like buffaloes because they went around in herds!' The interviewee highlights how science (both natural and social) often displays fashions.

"...if we have to write down the definition we tend to use the definition of the European Federation of Biotechnology, it's a definition we've discussed for many years in the Federation....It is one of the many definitions you can give. My colleague in the Agricultural University, also Professor in Biochemical Engineering, has collected something like 128 different definitions of biotechnology, not all of them that much different." KL, Scientific Director, Research School, The Netherlands

Quite apart from the enormous number of definitions that are said to exist, it is clear that the EFB's definition is designed to help facilitate co-operation between various interests and organisations by establishing some form of common framework.

Taking these three points about biotechnology together - difficulty in defining it, differences in opinion over its usefulness, and its multiple uses - it is clear that on a general level there are a range of conflicting and contradictory images and expectations attached to the term 'biotechnology'. This contested nature of the term 'biotechnology' has many practical implications which become apparent when particular characteristics of agro-food biotechnology, employed in public debates about its development and use, are examined. Two characteristics are examined below.

5.3.1 Traditional and modern biotechnology

The first characteristic of biotechnology centres on links between traditional and modern aspects. From the literature, one of the striking features of definitions of biotechnology is the constant reference to both traditional and modern aspects (see **Section 3.2**). According to the EFB's (1994) definition of biotechnology (the integration of natural sciences and engineering in order to achieve the application of organisms, cells parts thereof and molecular analogues for products and services), both traditional and modern aspects of biotechnology are incorporated. To take some more recent examples, in a review for *New Scientist*, Aldridge (1997) stresses that biotechnology is simply about using biological processes and, therefore, covers the fermentation of wine to transgenic animals. Similarly, Grace (1997:2), in a discussion of how biotechnology emerged, argues that the only difference between the use of these 'living things' in old and modern elements of biotechnology is not the principles behind them but the techniques for using them. A third recent example of connections made between 'past, present and future' forms of biotechnology is to be found in the FDF's *foodfuture*

campaign (1998). It suggests that through using 'biological processes to make useful products', traditional and modern aspects of biotechnology are connected in a linear fashion. These views are also echoed in the interviews:

> "I think there's a danger of getting caught up in semantics here. We need a simple and clear definition, one that does not make a distinction between traditional aspects of biotechnology and genetic engineering....I believe in evolution!" JM, Director of Research, Firm D (My translation)

But the idea that there is a need for a definition of biotechnology that incorporates traditional and modern elements points to inconsistencies with making links between them. From the research, (at least) three contrasting views on the links between traditional and modern aspects of biotechnology can be identified. The first is the tendency by a number of interviewees to make a distinction between traditional and modern aspects of biotechnology whilst recognising that there are links between them. As one interviewee notes:

> "[B]iotechnology is all the traditional things we do such as the development of new strains in plant breeding and animal husbandry...and the use of micro-organisms in the production of fermented products. So we have a lot of biotechnological instruments which have been used for hundreds and thousands of years. And now also it covers a number of new biotechnological methods, gene techniques, genetic manipulation, and the identification of certain genes so you can select them." BN, Advisor on Biotechnology, Agricultural Council, Denmark

In this case a linear model of biotechnology is presented, as to make use of the modern forms of biotechnology, such as rDNA technology, the more traditional technologies, such as tissue culture, fermentation and enzyme technology, have to be applied. A second view, connected to the first, centres on the belief that the reduction of biotechnology to its modern forms, especially rDNA technology, is neither accurate nor useful. One person interviewed remarks:

> "To me, biotechnology is a very broad concept which is also historical. It is not in anyway synonymous with gene technology. It is the deliberate use of...micro-organisms I guess, for...industrial purposes, and that has been going on for thousands of years...biotechnology is many things. Beer brewing as we have know it for many years is biotechnology...even bread baking...." JS, Research Secretary, Firm A, Denmark

A third view rejects this linear argument. Instead there is a need to distinguish between traditional and modern elements:

> "OK, well actually there...are two different meanings of biotechnology. So there is classical biotechnology in which you do fermentation, for instance, making bread, wine, beer etc....And then there is the more modern biotechnology which is everything involved, in making use of living cells to produce something which they normally don't produce." MH, Research Scientist, University, The Netherlands

Biotechnology's ancient links are wrongly equated with rDNA technology, the significance of inserting new genes provides a sufficient break to allow it to be treated as a distinct and separate technology (Sinsheimer, 1983; Bud, 1993).

The research highlights diverging views on the traditional and modern aspects of biotechnology and the connections between them.[15] On balance, the grouping together of traditional and modern elements - the fermentation of wine and the cloning of animals, for example - under the same heading for many interviewees is problematic. What is more, whilst in some cases the forging of links between traditional and modern aspects of biotechnology is seen as justifiable - for instance in the production of GMEs - in most cases it is contentious. Generally, then, this discussion provides further evidence for the conflicting and contradictory images and expectations attached to the term 'biotechnology'.

5.3.2 A natural process

A second characteristic of biotechnology centres on the connections with 'nature'. The literature on the history of biotechnology is replete with references to 'nature' (Levidow, 1996; Buttel, 1998). For example, the FDF (1996c) suggest that, historically, people have relied on natural (biological) processes for the provision of food and these form the basis of biotechnology. Madden (1995) argues that biotechnology involves increasing proteins which already exist in nature but on an industrial, large scale. Alternatively, Ganguly (1995) suggests that biotechnology allows food to be more 'naturally derived'. By contrast, Moser (1994) argues that biotechnology provides a new 'Eco Tech' paradigm which assimilates the capacity of 'natural cycles' to facilitate sustainable technology development. Alternatively, Young (1990) is of the opinion that

[15] Both the survey and interviews provide few clues as to exactly when 'modern' aspects of biotechnology began. Although the discovery by Crick and Watson (1953) of the structure of DNA, or the development of recombinant techniques by Boyer and Cohen (1973), seem the most obvious breaks with the past years they are never mentioned.

biotechnology is just about 'doing nature one better' as it allows approaches to agriculture to be developed based on natural ecosystems. And finally, for Morton (1995), biotechnology involves using genes and breaking 'nature's limits'. In this respect, biotechnology is seen to involve 'tinkering with nature' (Taverne, 1991) and even playing God (Kareiva and Stark, 1994; *Economist*, 1996c).

The link between 'nature' and 'biotechnology' also emerges strongly from the interviews. For example, some interviewees argue that biotechnology is a natural process:

> "...biotechnology to me... is natural....It is something...which is living....[that] is the reason why I call it natural....In Firm A we look at biotechnology, or the way we are promoting ourselves is natural, biotechnology we use it in a natural way, as natural as it could be. Or what we could say, we try to put the natural angle on the...on the technology." CB, Product and Marketing Manager, Firm A, Denmark

Although not all biological processes are necessarily living - enzymes for instance are biological but dead - for this person, the biological basis to biotechnology is indicative of its 'natural' disposition. Interestingly, and perhaps unsurprisingly, the interviewee also hints at the idea that the 'natural' quality of biotechnology is also important when promoting the company business interests. Another typical view is that biotechnology works with nature. One interviewee makes the point succinctly:

> "...you've basically speeded up nature and the natural selection that's gone on for thousands of years." DG, Technical Executive, Food Retailer, UK

Leaving aside the question of whether 'nature' would have led to some of the crossing of genes that have been undertaken - for instance, between a flounder and a tomato in Calgene's Flavr Savr™ tomato - many interviewees cite the fact that humans share most of their genes with other animals (98 percent with chimpanzees) in support of the notion that biotechnology is not really about the inter-species transfer of genes.

These interviewees make a clear link between biotechnology and nature, but as might be expected, given the problems with defining biotechnology, some interviewees see the link as problematic. For example, one research manager comments:

> "Well natural is anything that is coming directly from nature, or coming from nature after a natural conversion. And let's say enzymatic or microbial conversion is considered natural because it is happening in nature. I must admit there is a very large grey area.

> For instance, we are considering to use co-factor dependent enzymes, because they are very interesting for various conversions. The problem is how you co-factor, which is mostly too expensive. We have found a way to use...let's say standard electrical current, in order to avoid the use of co-factors. That means the enzymes are driven by current, the conversion is done by enzymes, so we consider this as natural. But is it natural? Because you apply outside energy...." MO, Research Manager, Firm C, The Netherlands

There is clearly a general difficulty with defining 'nature'. Whilst there is a growing consensus on the difficulty in separating 'nature' from, for instance, 'society' (Dickens, 1996; Robertson, et al., 1996), this is reflected in the interview extract in terms of the difficulty in specifying what nature entails. Moreover, there is an issue of what actually constitutes interfering or manipulating nature. For example, when would interfering with genes be unnatural? This is especially relevant given the belief of some writers that the debate about whether 'biotechnology is natural' is illogical as there is a degree of interference with nature even with human existence (Macer, 1996:10).

But as Bloor (1982:198) points out 'Men (sic.) use their ideas about Nature to legitimate their institutions'. Therefore, whilst avoiding an in-depth discussion on the construction of nature, it is instructive to note that the juxtaposition of the 'biological' onto the 'natural' appears in some instances to be an attempt to validate biotechnology in the context of societal needs. In other words, whilst there is a belief that biotechnology is natural, after further investigation this notion is considered sufficiently ambiguous to require qualification. In this second characteristic, then, the difficulty in offering a precise definition of biotechnology is linked to the different ways people involved in biotechnological innovation conceptualise and interpret the 'natural'. Nevertheless, in public debates on biotechnology, the practical benefits of making links between 'biotechnology' and 'natural' are considered a necessary part of public information campaigns.

5.3.3 Some reflections on the contested nature of biotechnology

This second part of this chapter seeks to explore how biotechnology is conceptualised and interpreted by key individuals involved in its innovation. Whilst it is too early to make any unequivocal statements about how these differing conceptualisations link into the broader debate about innovation in biotechnology, four useful sets of ideas can be drawn from the evidence. First, there is considerable

difficulty in specifying 'biotechnology' as it is seen to refer to a wide range of technologies and techniques. Superficially, at least, this idea is supported by the notion that biotechnology is not a single discipline or area of knowledge (see **Section 7.3**). Nevertheless, this difficulty in specifying 'biotechnology' has not prevented attempts at providing a working definition which is necessary for many areas of social activity, such as public information campaigns. The importance of defining 'biotechnology' is especially important given that rDNA technology is relatively new and there is relatively limited experience of its use.

Second, the differences in views over what 'biotechnology' entails attest to the significance of the term being used to achieve different ends. Illustrative of this multiple dimension to the term 'biotechnology' is how it is associated with public information strategies:

> "I would say that biotechnology is the new tools and the old traditional tools which we have been using for hundreds of years in the dairy industry and the food industry....It is very difficult to define because you have some techniques which are accepted just because they are old. And then you have some new techniques which are not accepted because they are new but the results which you can get from these new techniques are exactly the same as you can get from the old techniques. And it is very confusing to say, to explain and understand that you can get the same results with the old-fashioned methods as you can get with these new maybe scary methods....It is scary to the consumers because researchers use their own languages...." SH, Advisor on Biotechnology, Danish Dairy Board, Denmark

The links between traditional and modern biotechnology do not take place in a social vacuum and, it can be argued, are directed towards achieving different social objectives as society's social needs have evolved.

Third, notwithstanding the ambiguities highlighted above, the term 'biotechnology' remains in widespread use to describe and promote 'scientific' and 'technological' activities associated with the development and use of biological knowledge. What is more, there is some sense that it is preferred to more specific and perhaps less attractive terms such as genetic engineering and genetic modification. Interestingly, in the latest EU Fifth Framework document, biotechnology has been

subsumed by the broader title of 'the life sciences' (CEC, 1998b).[16] Reasons for the poor publicity of the term is provided by an interviewee:

> "there are more people looking at biotechnology than actually involved in the actual R&D....because of all the hype associated with it....we shot ourselves in the foot in the early years by hyping it up....now public acceptance is critical." JM, Director, Biotechnology Trade Organisation, Denmark

Finally, 'biotechnology', is more than a technological term. The debate around 'what is biotechnology?' is influenced by broader objectives associated with its explanation. Thus when it comes to influencing public perceptions it is clear that connections between 'traditional' and 'modern' aspects of biotechnology are strongly made, connections valued when trying to convince a sceptical public. 'Biotechnology', then, simultaneously refers to a set of technologies and techniques, and broader political projects.

Taking these four points together, there is a clear sense that the term 'biotechnology' is strategically used in different contexts. It is neither a 'natural' nor a 'universal' concept. It absorbs aspects of the contexts it occupies and creates. It is a contested term *par excellence.*

5.4 Discussion

The preceding discussion presents arguments and examples of what can be construed as the 'pragmatic' and 'ontological' aspects of 'what is agro-food biotechnology?' It remains to consider how these two dimensions of agro-food biotechnology are connected. At the most general level, a dialectical relationship between the actual developments in agro-food biotechnology and how they are conceptualised and interpreted can be identified. The success of applying rDNA technology to produce GMEs is clearly demonstrated in the research. Leaving aside 'technological' issues that might suggest the relative ease of producing GMEs, one of the most important factors to influence this success is the tendency in the industry to consider them as physically identical to those enzymes produced using non-rDNA

[16] The management consultants Ernst & Young have also moved from using the term 'biotechnology' (1994, 1996) to the notion of 'life sciences' (1998) in their reports.

technology.[17] As GMEs are constructed as identical to non rDNA enzymes, they have not been required to undergo any additional regulatory or public inspection procedures. In one sense, then, GMEs can be thought of as 'ontologically' similar to non rDNA technology enzymes as little difference is made in the way the non rDNA enzymes and GMEs are conceived by both the manufacturers and regulators involved in the development and application of GMEs.

A second point centres on the practical implications of defining biotechnology. Some of the difficulty in being precise over 'what is (agro-food) biotechnology?' is reflected in the differences in opinion over current developments in agro-food biotechnology. But this uncertainty with the term 'biotechnology' runs against the precision, or at least the need, generally characterising science and technology. It is often argued that one of the key features of technoscience is its repeatability; that is, if the conditions of an experiment are replicated, the results are also the same (see **Section 2.3**). But this repeatability is also required for certain areas of social activity. In the case of biotechnological innovation, an accurate understanding of what biotechnology entails is required for devising regulatory systems which provide protection consistently (see **Section 6.3.4**). This need for consistency in biotechnology is especially important given that the application of rDNA technology to agro-food systems is a relatively new activity and there is little experience in managing the technology in this area. But the critical area of contestation associated with the 'ontological' aspects of biotechnology makes it difficult to systematically deal with many of the social activities linked to the 'pragmatic' elements of biotechnology.

As a final point, how biotechnology is conceptualised and interpreted may also be connected to the position of the actors. Although speculative, from the research, individuals 'directly' involved in the innovation of agro-food biotechnology appear less optimistic and more insecure about both the pragmatic and ontological aspects of agro-food biotechnology than those who are more distant from it; interviewees involved in the actual R&D of biotechnology are more likely to highlight its problems and limitations compared to many of the interviewees from, for example, trade lobbies and food retailers. This discrepancy in views can be put down to a lack of awareness and

[17] It is worth noting that non-rDNA enzymes (wild enzymes) often exist as part of a cocktail of enzymes, such as in animal rennet.

information about the developments in agro-food biotechnology.[18] This is borne out by further evidence on the diffusion and dissemination of information about developments in agro-food biotechnology. In the UK, for instance, over the last two decades, there has been a gradual shift from the public to the private sector in the way agro-food (bio)technology R&D has been funded and managed (Munton et al., 1990). This has been accompanied by a move from a more general R&D strategy based around a shared information base to one that encourages greater control and awareness over intellectual property rights (IPR) and, in turn, secrecy. Similarly, the scale and scope of collaboration within the agro-food biotechnology sector, especially between interests that 'develop' and 'apply', is limited (Ahson, 1996a). Combined, these two aspects point to a deficiency in the dissemination of information about (agro-food) biotechnology (Ahson, 1997). In turn, this deficiency can be linked to inconsistencies in the images and expectations of 'biotechnology' associated with the pragmatic and ontological aspects of 'what is agro-food biotechnology?' (Ahson, 1998).

From the new analytical framework developed for examining biotechnological in **Chapter 2**, this chapter has taken a cue about the possible multi-dimensional character of biotechnology. Fundamentally, the links between the 'pragmatic' and 'ontological' aspects of biotechnology identified in this chapter suggest that the question 'what is agro-food biotechnology?' is intimately connected to the activities of biotechnological innovation. This second issue is examined in **Chapter 6**.

5.5 Summary

This chapter examines the first research question 'what are the main developments in agro-food biotechnology?' Two dimensions of this question are important. The first is 'pragmatic'. It concentrates on identifying and describing elements of agro-food biotechnology that are actually being developed and applied. Using an approach focusing on developments in specific areas of agro-food biotechnology, it is suggested that there are several radically diverging, and possibly contradictory, tendencies taking place. For example, most of the major developments to

[18] Even more speculatively, having said that biotechnology has political uses, it perhaps makes sense for those people involved directly in the innovation of (agro-food) biotechnology not to publicise its limitations.

date involve food processing aids and raw materials for food provision. It follows, that the majority of developments and benefits seemed to accrue to producers in agro-food systems with consumers unlikely to notice or experience any significant difference in their food supply. The second dimension is 'ontological' and concentrates on the differences in how biotechnology is understood. The research reveals problems in trying to define or ascribe meaning to biotechnology, as well as a huge variation in the usage of the term by people involved in biotechnology's development and application. This difficulty highlights that 'biotechnology' occupies a contested terrain. Given this, and given that 'biotechnology' is used to refer to a range of technologies and techniques, rather than view it as a universal concept it has to be examined and comprehended through the contexts it occupies and creates. Not surprisingly, these issues are an important aspect of understanding the nature and characteristics of biotechnological innovation. In the next chapter, the second research question, 'how does innovation in agro-food biotechnology take place?' is examined.

6

HOW DOES BIOTECHNOLOGICAL INNOVATION TAKE PLACE?: SEVEN STORIES ABOUT GENETICALLY MODIFIED ENZYMES

6.1 Introduction

In this second empirical chapter, an account of biotechnological innovation is given. In **Chapter 2**, an analytical framework for biotechnological innovation is developed. It is proposed that innovation in agro-food biotechnology needs to be conceived of in terms of a network which links 'social' and 'technological' elements together as part of a broader strategy to accumulate capital. This chapter evaluates this conceptualisation of biotechnological innovation through presenting seven stories about the innovation of GMEs.

Although the notion of a 'network' does not provide a precise set of indicators to help explore the main characteristics of biotechnological innovation, it does focus attention on certain features and underlying processes, such as social relations, at issue in these stories. In the stories, the network that makes up biotechnological innovation is seen to go beyond the boundaries of the major laboratories and firms viewed as responsible for the innovation. Indeed, in keeping with the notion that networks represent a particular spatial form or typology which dissolve categories, such as nations, regions, and institutions on the one hand, and the 'social' and 'technological' on the other (see **Section 2.4.2**), the main characteristics of biotechnological innovation are framed within the mapping of the network itself. Unavoidably, then, the account is not constrained within particular boundaries, and the element of the network that is identified has much to do with the execution of the research project itself, constrained by time and resources (see **Section 4.4.2**).

Whilst this part of the research is organised around two GMEs, as noted in **Section 4.4**, the aim is not to undertake a comparative study between them. Rather, elements of innovation of the GMEs are drawn out and combined to present a

picture of biotechnological innovation.[1] The descriptions try to show the connections and interactions between various cultural, economic, political, scientific, social and technological elements in biotechnological innovation, some of the features of where and how innovation takes place, and the key actors and institutions that shape these arrangements and interactions. This chapter is divided into three main parts. **Section 6.2** provides some general information on the function and production of GMEs. **Section 6.3**, the longest section of this chapter, sketches out the seven stories of the innovation of the GM chymosin and GM xylanase. **Section 6.4** draws out some general points of interest about 'how' innovation in agro-food biotechnology takes place.

6.2 Genetically modified enzymes: an overview

Enzymes are proteins which act as catalysts facilitating biochemical reactions through which all biological material is built up and ultimately broken down. Enzymes have a long history of use in agro-food systems (Pitcher, 1986:62; Ducastaing and Adrian, 1990), dating back to the production of wine, bread and cheese over many thousands of years (AMFEP, 1995a:1; Gist-brocades, 1991; FDF, 1996c; **Section 3.3.2**). Only recently, since about the 1950s, have new ways been discovered to utilise enzymes in the provision of food.[2] For instance, in the baking process, they help make up for flour deficiencies, extend shelf life and improve texture, crumbing and crusting of baked goods; in brewing, they improve filtration and enable the production of low-carbohydrate (lite) beer; in dairy products, they break down lactase (milk sugar) which cannot be digested by many people, as well as increasing the stability and shelf life of dairy products; in fruit juices, they reduce processing costs; they are employed in the production of HFCS from starch widely

[1] Despite claims of rigour and detail in many recent accounts of biotechnological innovation, they can only provide partial descriptions. Take for instance Rabinow's (1996) study of PCR. Although on a theoretical level he highlights the complexity of the various aspects and interests involved in innovation, in empirical terms his analysis is limited because it is confined to the actors and activities within a firm. What such accounts point to is the need to devise more holistic accounts of biotechnological innovation which the use of the 'network' aims to achieve.

[2] It is interesting to note that European based companies dominate the production of food enzymes with approximately 70 percent of world market share (AMFEP, 1995a:2; **Section 4.4**).

used in soft drinks and confectionery; they improve the digestibility of plant protein; and raise protein yield from animals and fish in the meat and fish-meal industries (AMFEP, 1995a:3).

Although enzymes are found in all living cells,[3] the enzymes required by the food processing industry are produced using various micro-organisms such as bacteria (e.g. *bacillus*), yeast, and fungi (e.g. *aspergillus*) (ibid.:4). Once a specific application for an enzyme is identified - the need to clarify fruit juice, for instance - a screening process takes place among micro-organisms until an enzyme with the required properties is found. Following this, the micro-organism containing the desired enzyme is inserted into large tanks or fermenters (50 000 litres or more) of a growth medium with nutrients that allow the micro-organism to multiply rapidly and produce large quantities of the desired enzyme. The resulting broth is then purified by removing solid waste and concentrated by removing water. Finally, the concentrated enzyme is formulated into sizes and form - liquid or solid, for example - depending on the requirements of the user.

Today, rDNA technology plays a crucial role in the industrial production of enzymes (Pitcher, 1986; Teuber, 1993; Hodgson, 1994; Cowan, 1996; Breaker, 1997). The use of rDNA technology in enzymes can be done in three main ways (AMFEP, 1995b:5). The first involves the production of an already identified enzyme in greater quantities. Here the host micro-organism may be genetically modified to contain several copies of the gene coding for the enzyme, thus increasing production rates. This is known as homologous genetic modification because the original gene in the original or closely related micro-organism is used.[4] The second method, heterologous genetic modification, arises when the desired enzyme is identified but its normal host micro-organism is unsuited to large-scale production. In this case, the micro-organism may not grow well in fermenters or may exist only in plants and animals from which it is difficult to obtain large quantities.[5] Here the gene encoding for the enzyme is introduced into a 'safe' micro-organism (such as

[3] Critically, it must be recognised that although enzymes are biologically active proteins they are not 'living' as they cannot reproduce themselves (Lawrie, 1997; Voragen, 1997).
[4] GM xylanase used to increase the volume of bread in the baking process is produced using this method.
[5] Such as in the production of GM chymosin used to clot milk in cheese production.

aspergillus) leading to the genetic ability to produce the enzyme being transferred to a different organism. The final method, protein engineering, is used when an enzyme performs most but not all the desired functions; for instance, it may not function well under extreme temperatures or varying pH levels. In such cases, a highly specific change in the gene coding is undertaken which results in a modification of the protein of the enzyme.[6] Critically, in all three cases, rDNA technology is employed at the initial stage of the innovation process where the GMO is produced, rather than at the stages of reproducing and manufacturing it. Examples of GMEs used in agro-food systems are listed below in **Table 6.1.**

Table 6.1: GMEs used in agro-food systems

Principal enzyme activity	Application
α-acetolactate decarboxylase	brewing
α-amylase	baking, brewing, distilling, starch
catalase	mayonnaise
chymosin	cheese
ß-glucanase	brewing
α-glucanotranserase	starch
glucose isomerase	starch
glucose oxidase	baking, egg, mayonnaise
hemicellulase	baking
lipase	fat, oils
maltogenic amylase	baking, starch
microbial rennet	dairy
phytase	starch
protease	baking, brewing, dairy, distilling, fish, meat, starch, vegetables
pullulanase	brewing, starch
xylanase	baking

Source: AMFEP (1995c)

6.3 Seven stories of biotechnological innovation: GM chymosin and GM xylanase

GM chymosin is currently used in the dairy industry in the manufacture of cheese, although it is difficult to be precise as to the extent of its use (Teuber, 1993). GM chymosin is used to break peptide bonds in milk helping it to coagulate, the first step in the production of cheese (Pilnik and Voragen, 1990:321; Dekker,

[6] For example, the development of a GME which turns starch into high fructose sweetener found naturally in honey and fruit.

1994:138). The GM chymosin (enzyme X) investigated in this study is produced by a Danish firm (firm A) which has been involved in the production of cheese coagulants for over a century and is now one of the largest manufacturers of coagulants in the world (it has about 25 percent of the world market). Enzyme X is part of firm A's portfolio of coagulants for dairies and cheese makers around the world which also includes animal rennet, the traditional source of chymosin, and microbial coagulants produced by fermentation. Whilst there are many reasons for having a GM chymosin, one of the main ones is the rising cost of calf stomach (the natural source of chymosin for cheese making) which is increasing steadily.

GM xylanase is generally used in cereal processing such as bread making, brewing, starch gluten separation in wheat processing, and in animal feeds with a cereal base (Voragen, 1997). In specific terms, it has a positive effect on the baking quality of flours as measured by bread volume and crumb structure (Pilnik and Voragen, 1990:322). Xylanase ranks under the broader category of hemicellulases which are all enzymes active on hemicelluloses and used to break down a range of carbohydrates. It is the most effective hemicellulase used in the bread baking process (Lawrie, 1997). The GM xylanase (enzyme Y) examined in this study is produced by a large food ingredients company (firm C) based in the Netherlands. Firm C, however, is part of a very large agro-food and consumer durable multinational (firm D) which has operating companies in over thirty countries. Enzyme Y is mainly used in the redistribution of water to improve dough tolerance and increase the volume of the final bread product.

6.3.1 Making milk coagulate and water stand: ideas for GMEs

There is considerable ambiguity in the literature on where ideas for innovations come from. Whilst innovation is studied at length, the source of innovation is often ignored. For example, in the widely criticised but still dominant 'linear model' of innovation (see **Section 2.2**), although the different stages of pure and applied research and how they link into product/process development and production are frequently discussed, the issue of how the ideas come about in the first place is surprisingly neglected (see, for instance, Malecki, 1997:51-61).

Superficially, some writers argue that innovations come about through 'passion, rivalry, chance or personal obsession' (Ford, 1995:236). A classic interpretation of this position is Crick and Watson's discovery of the helical structure of the molecule which was achieved in defiance of institutional policy and when the laboratory was closed (Watson, 1968; Strathern, 1997). By contrast, some writers argue that contrary to popular opinion, discoveries, such as the cholera vaccine by Pasteur, come about through the systematic application of scientific methods to particular problems (Root-Berstein, 1989). Notwithstanding these differences, there is some sort of consensus on the notion that ideas for innovations stem from competitive pressures and technological opportunities that exist in the market on the one hand (Howells, 1994; Morris and Westbrook, 1996), and how firms develop and adapt their business strategies to deal with them on the other (Hippel von, 1988; Afuah, 1998).

Generally, in firm A ideas for enzymes come from product development teams:

> "...our sales guys, my team, maybe a scientist would be participating in a seminar, maybe taste the cheese and then get an idea....And then of course we would have to...see what is the potential of things, together with what is possible....And then if it is...possible, or if it looks like there is a great potential, we have to look into the R&D about the possibilities..." CB, Product and Marketing Manager, Firm A, Denmark

This account suggests that the ideas for GMEs emerge from outside the firm in accordance with particular problems which have been identified in the market. But the idea for enzyme X came from a rather different source:

> "The management decided...to make these products (GM chymosin)....It was mainly in-house because...we knew that these techniques (rDNA technology) were coming and therefore possible. And we wanted to supply enough of this enzyme. It is the best, you have a whole range of enzymes for cheese making but this one is the best....you can see it by the kind of prices customers pay....There are several producers of chymosin....[But] enzyme X is the best... All companies had decided to develop this enzyme because everybody believes it is the best." MH, Research Manager, Firm A, Denmark

The emergence of enzyme X, then, was part of a strategic decision made by senior management in firm A in the early 1980s to apply rDNA technology to the innovation of enzymes. Indeed, according to one source it is said to have been 'the specific idea of the managing director at the time who felt that the GME market was

the logical step in the development of firm A's product portfolio'. Given this, and given that the profits in the enzyme market remain small (Cowan, 1996), with enormous competition between a relatively small number of large players (Pal, 1992), any means by which profitability can be increased through improved technological developments is seen as critical. The application of rDNA technology to produce coagulants was therefore influenced strongly by the threat from other competitors in the enzyme market who appeared to be more familiar and advanced with rDNA technology. In fact according to the research manager for enzyme X, under pressure from other companies who were developing rDNA technology, it is clear that this route was 'the only way an unlimited supply of this enzyme (chymosin) can be produced'.

The idea for enzyme Y also appears to come from 'within' and, in particular, from two developments taking place in firms C and D in the late 1980s. The first centred upon an increased knowledge of what was happening in the bread baking process among individuals working in R&D in the two companies, especially in relation to the raw materials used in bread making and the role enzymes played in them. As the research manager for enzyme Y describes:

> "if you know in detail what kind of steps are taking place then you can say well we can use an enzyme specifically for this conversion, or we can use an enzyme to get that effect. Initially we were developing enzymes just...we found an enzyme and then we said 'what can we do with it?' And now we are looking very closely to the various processes and try to think of enzymes which might have an effect and then we are looking for the enzyme. So that is in effect the other way around [You've turned it on its head] More or less, it is not completely but that is the way we like to work at the moment." MO, Research Manager, Firm C, The Netherlands

In the case of enzyme Y, the increased knowledge of hemicellulases played an important role in the development of a GM xylanase as the precise characteristics which were required to improve it were identified.[7] This understanding opened up potential market opportunities and led to an increase in R&D. The second development that is said to be important for enzyme Y was luck:

[7] It is instructive to note that the specific characteristics of bread also influenced the development of enzyme Y. According to one bakery specialist in firm C, there are many 'unknowns in the bread dough' and, therefore, as enzyme Y was developed the conditions for its use also had to be considered. This was done on a trial-and-error basis in an in-house bakery.

> "...it was part of the accidental discovery. Because when...I think it was a pectinase that was originally put in a dough system produced an effect, and then people were interested why you got an effect. And then it was a case of trying to identify which of the other activities that were present were actually having an impact within the dough system." DW, Business Unit Manager, Firm C, The Netherlands

At first there is a hint that enzyme Y came about purely coincidentally. Nonetheless a careful examination of the innovation of enzyme Y reveals that the discovery emerged within a fairly structured framework which was generally focused on improving enzyme activity in bread baking. In this respect, the discovery of enzyme Y seemingly emerged from within firms C and D as a possible market opportunity. But according to a senior academic from the agricultural university involved in its development, enzyme Y is 'not a solution to a problem'. That is, the development of enzyme Y is part of a broader strategy to build up expertise in the enzyme market from which to develop and exploit market opportunities.

There are some clear differences in how the ideas for enzymes X and Y came about. Enzyme X can be viewed as both a radical departure from firm A's activities, and more generally, in developments in food grade enzymes. There are strong indications to suggest that enzyme X was the first food grade GME to be developed and used in Europe and the length of the innovation period (over 10 years) reflects the many new 'social' and 'technological' issues that had to be overcome as shown in subsequent stories. Therefore, the idea for enzyme X appears as a bold strategic move by firm A to maintain its competitive edge in the chymosin market by developing rDNA technology. According to one director in firm A, 'this was driven by the fluctuation and availability of animal rennet and the emergence of BSE'. The importance of BSE in influencing the move towards rDNA technology was borne out later when one of the chymosin production sites in the UK was subsequently closed. By contrast, the innovation of enzyme Y took place several years later, and emerges from a gradual build-up of knowledge on bread baking and a desire to extend the product range of firms C and D. The innovation of enzyme Y reveals the relations between firms C and D: firm D bought firm C to enhance its knowledge and expertise in speciality chemicals which could be used in the production of agro-food products and which, according to one research scientist in firm C, is 'part of a total food approach'. Critically, by buying into different aspects of rDNA technology, firm D highlighted the importance of this technology more generally for food provision.

6.3.2 Putting rDNA technology to work: cloning hosts and the need to co-operate

The desire to employ rDNA technology in the innovation of enzymes X and Y brought about the need to co-operate. Much has been written about the range of co-operative agreements which characterise biotechnological innovation. In particular, strategic alliance activity (SAA) is considered to be a dominant feature of innovation in this sector (see, from among many examples, Hagedoorn, 1993; Duysters and Hagedoorn, 1995; Ahson, 1996a; Prevezer and Toker, 1995). SAA is a wide ranging term but is generally used to refer to agreements designed to enhance the long-term strategic objectives of organisations and ranges from R&D collaboration to joint ventures (Ahern, 1993; Arthur Andersen, 1994). These co-operative agreements take many forms. Typically, they involve links between small DBFs and universities (Blumenthal et al., 1996), and large pharmaceutical companies and DBFs (Kenney, 1995; Haber, 1996). More recently, there have been mega-mergers, such as between SmithKline Beecham and Human Genome Sciences (Edgington, 1997) or the acquisition of Gist brocades by the chemical firm DSM (*Nature biotechnology*, 1998a).

Once the decision was made to develop a GM chymosin, firm A had to decide upon the source (host) to produce it (see **Section 6.2**). As the research manager for enzyme X describes:

> "...there were plenty of options...so we started with one organism the *e coli*, then tried some others...and we analysed and characterised and see what we got out of it, and looked at the yields and the possibilities for increasing it. And we tried quite a lot until we decided we were satisfied with the *aspergillus*....There is more work with *e coli*, it is more difficult to purify...there was some uncertainty...it is difficult to produce...it was more complicated. And further we were not sure about the consumers...we were not sure how their attitude would be." MH, Research Manager, Firm A, Denmark

The choice of *aspergillus* for the host of enzyme X was motivated by several factors. First, given the expertise available to firm A, they found it technologically the easier to handle; in fact, *aspergillus* is generally seen to be a good producer of extra-cellular enzymes (Bigelis, 1993). Second, *aspergillus* was already used widely in the production of food and, therefore, was considered safe to use and acceptable to the public. Interestingly, according to one interviewee in firm A, 'it was felt that the

public would have reacted negatively to *e coli* because it is a bacteria rather than *aspergillus* which is a fungus'.

But firm A lacked the necessary experience and expertise to clone the chymosin gene into *aspergillus*. A partner had to be sought. One option was an American firm (firm B) based in San Francisco which had been producing GMEs for a number of years using *aspergillus* as the source:

> "...if we look at them they have been producing enzymes for many years they know *aspergillus*....At the time we realised that we didn't have the knowledge to go in this area....If you are not in fermentation with these kind of organisms or these kinds of technologies then you would prefer to go to some other companies....But Firm B was producing enzymes...we have a long contract with them for the time being." RL, Production Director, Firm A, Denmark

Firm B was not the only company that was approached during the initial stages of the cloning of enzyme X. In fact two companies in Denmark - a large brewing concern, and a multinational pharmaceutical company - were also approached. In the first case, the necessary expertise to undertake the cloning of *aspergillus* was not there. In the second case, the pharmaceutical company was viewed as a rival as it had begun to use its expertise in rDNA technology to enter the food enzyme market. Mindful of this, the link between firms A and B was seen to be a logical marriage as the research manager for enzyme X remarks, 'we are the main dealer in the world in chymosin and they are the largest company in genetic engineering.' Thus the cloning of enzyme X was based on a clear division of labour between firms A and B.

Usually, firm D undertook all the rDNA technology work for firm C. But in the case of enzyme Y, it did not have the specialist expertise to undertake the homologous transfer for the xylanase and, therefore, had to find a suitable partner. Whereas firm A worked with a potential competitor, firms C and D decided to work with a number of public research organisations of which the Netherlands Organisation for Applied Scientific Research (TNO) was the most important, which had relevant cloning expertise.[8] As a member of the TNO team involved in the project describes:

[8] This TNO institute is one of 15 dedicated to the food, chemical and pharmaceutical industries which conduct 'applied' research of use to industry. In the area of testing food for genetic modification, TNO is one of the dominant world players (Steinberg, 1997a).

"we knew the technology and they didn't at that moment. When we started they had no experience with fungi at a micro-genetic level, so they had to contract somebody or get somebody in-house who does it for them. But I think that is a typical moment when you look around as a company and see who is able to do it for you." MO, Head of Gene Technology, Research Institute, The Netherlands

As with enzyme X, *aspergillus* was used as the host for enzyme Y. This decision was motivated mainly by the existing expertise and experience with this growth organism in TNO. The cloning period for enzyme Y was much less than for enzyme X because by 1992 important improvements had occurred in the process which speeded it up. The working relationship with TNO was preferred over other firms because apart from their obvious knowledge and expertise in the area of *aspergillus* and food grade enzymes, they were viewed, according to one research scientist in firm C, as 'less of a rival'.

The co-operative element in the development of enzymes X and Y is clearly highlighted in the story above, although there are fundamental differences between the two GMEs over how the co-operative work became manifest. For example, enzyme X appears to involve a partnership of equals where the division of labour is split between expertise in chymosin manufacturing, and knowledge and experience of using rDNA technology. By contrast, for the cloning of enzyme Y, the relationship between firms C and D and the TNO seems more contractual and short-term. None of this means that the role of the cloning is any less important for enzymes X and Y, even if the cloning and application of rDNA technology had become easier by the time enzyme Y was cloned. As one research manager in firm A notes, 'the time taken to clone hosts has decreased from 2-3 years to about 6 months'. Finally, the choice of *aspergillus* points to the importance of consumer opinion and not only technological considerations for biotechnological innovation.

6.3.3 Paying for research: public funding for biotechnological innovation

The public funding of biotechnology played an important part in the innovation of enzymes X and Y. There is much debate about whether the public funding of R&D contributes to economic growth (Kealey, 1996); many sources still consider it to be critical (WEF, 1997). Overall R&D expenditure in the Netherlands has declined from 2.3 percent of GDP in 1988 to 1.9 percent in 1993, of which 53 percent was

conducted in the private sector (Omta, 1996:25; IMD, 1996:523), and the total figure is well below the OECD average (MEA, 1995a:16). For biotechnology, since the early 1980s, the Dutch government has sought to stimulate its development and application, and invested over Dfl 400 million[9] in the 1981-93 period (MEA, 1995b).[10] In Denmark, total expenditure on R&D in 1994 was 1.8 percent of GDP, with business activity accounting for 58 percent of it (IMD, 1996:523).[11] But biotechnology seems to have disproportionately more public money spent on it, and it is estimated that over the last decade Denmark has invested more public money in biotechnology R&D per capita than any other country, even the US (DRC, 1993). At the heart of Danish attempts to stimulate the biotechnology industry have been a series of research programmes organised by the Government to encourage technological innovation networks.[12]

---

[9] At current rates (November 1998) Dfl 1 = £0.33, DKK 1 = £0.10, and ECU 1 = £0.70. These figures must be treated with some caution as over the last few years currency rate fluctuations have been large.

[10] A number of means have been employed to encourage R&D (MECS, 1992; see also **Section 4.4**). The innovation-oriented research programmes (IOPs) were launched in 1981 and administered by the Ministry of Economic Affairs (MEA). These included biotechnology and involved encouraging the public and private sectors to work together. In addition, the MEA has set up a number of instruments for industry such as the Technology Promotion Scheme (PBXS) and the Technical Development Credit Scheme (TOK) for promoting R&D in and for industry. As well as funding the 13 universities, the Government also supports a number of research institutes in the Netherlands such as the TNO which are administered by the Netherlands Organisation for Scientific Research (NWO) and the Royal Dutch Academy of Science (KNAW) (Omta, 1996:31). More recently, following a white paper 'Kennis in Beweging' (Knowledge on the Move), the Dutch Government have felt the need to set up a number of leading technological institutes (TTIs) (KNAW, 1996). The main aim of these TTIs is to carry out research in areas that are highly relevant and useful to business enterprises, and designed to build on existing strengths of Dutch R&D infrastructure (MEA, 1996). One of these institutes focuses on food technology and is sponsored by firm D. Curiously, Dutch public sponsored R&D on 'science' (such as university spending) is managed by the Ministry of Education, Culture and Science (MECS) whereas R&D on 'technology' is now dealt with by the MEA.

[11] The UK spent 2.18 percent of GDP on R&D with 66 percent of activity in the private sector.

[12] The first Danish biotechnology programme (1987-90), endowed with DKK 340 million, was set up to develop further the R&D and educational system and to provide a strong foundation for utilising the possibilities of biotechnology (see also **Section 4.4**). One of the major goals of the programme was to ensure an adequate supply of qualified graduates and encourage co-operation between the public and private sectors as well as between universities and research institutes. In addition, the programme aimed to strengthen international co-operation and to ensure that Danish research was carried out at an international level. The second programme was the DKK 400 million, Biotechnological Research and Development Programme, running from 1991 to the end of 1995. It also aimed to sustain and improve Danish research in biotechnology, especially in terms of encouraging co-operation between universities and the biotechnology industry. In addition, there have been a number of other government sponsored programmes for R&D in the agro-food sector which have had aspects of biotechnology, such as the Research and

The importance of public funding for R&D was influenced by a number of factors. In the Netherlands, for instance, one senior government official observes:

> "...what I have seen over the last 10-15 years is that big multinational companies in their research programmes also have shifted from the more fundamental research to more applied research, to research far more serving today's needs of the business. At the same time there has also been a trend in these multinationals of...expanding their business into other countries....So that is one of the explanations that over the last 10 years, expenditure of companies in research in the Netherlands has been declining." RW, Director-General of Science, MECS, The Netherlands

In Denmark the reasons behind public funding of R&D were not dissimilar:[13]

> "... our industry does less research compared to most other countries, for one or two reasons...one is that we have a few very big companies, mostly big companies do research. And second...a lot of industry is in the food industry where traditionally research is lower and so...if the public sector doesn't do research there is no research." KM, MP and Chairman of Scientific Committee, Folketing (Parliament), Denmark

In the Netherlands, however, the particular focus on biotechnology came about from a belief of many key individuals in Government that it was a strategic technology and one that needed to be stimulated. One of the key politicians involved in promoting biotechnology notes that:[14]

> "at the beginning of the 80s there was a political mind that one has to stimulate technology to become economically competitive....So I thought this was a unique possibility to demonstrate to the politicians that science should be stimulated....And the second point was to demonstrate that scientists could do something for society and do it in a concrete way and this could be done by creating a programme and have a lot of scientists participate...The original start came from the Ministry who did the first study, The Ministry of Education and Science, and at that time we had a Department of

---

Development Programme for Food Technology (FØTEK 1 and 2) over the 1990-94, and 1994-97 periods. Endowed with budgets of DKK 525 million and DKK 330 million respectively, these programmes aimed to strengthen the position of the Danish food industry in the international market through combining basic knowledge from universities to the needs of industry (FØTEK, 1993, 1995).

[13] As an aside, the need to improve the basis of Danish R&D in biotechnology has not always come about through strategic planning. For instance, according to its director, the Danish National Research Foundation (NRF), established in 1991 to enhance Denmark's research development capability including biotechnology (DNRF, 1994), came about through an extra DKK 2 billion that 'appeared to be floating around after the sale of a government insurance company'. Whilst the Government wanted to encourage R&D they had to maintain a ceiling on the budget. Thus the NRF was set up out of funds from the sale of the insurance company and not out of the normal budget of the Ministry of Research.

[14] According to one government advisor on biotechnology, the move towards greater involvement in R&D was mirrored in a broader shift in the political environment in the Netherlands. Essentially, the shift from a socialist to a more liberal political environment from the early 1980s saw the Government become more sympathetic and active in the stimulation of science and technology.

Technology...." RS, Professor of Biochemistry and Senior Government Advisor, The Netherlands

Leaving aside the curious division between 'science' and 'technology' displayed by ministerial responsibility, according to the manager of biotechnology projects at the MEA, the Government aims to 'set up a good infrastructure to encourage work between universities, industry and research institutes'.[15] The same was true in Denmark as although the Folketing (Danish Parliament) is generally involved in setting the budget parameters for R&D in science and technology, in the case of biotechnology, they were more directly involved as biotechnology was singled out as a specific area of research and had its own budget.

At the same time, as governments in Denmark and the Netherlands began to stimulate biotechnology, the CEC also sought to encourage and promote biotechnology through a number of research activities (Economidis, 1993; CEC, 1998b). One person at the CEC describes the importance of biotechnology:

"...it has tremendous power, genetic engineering. And power leads to a thing called wealth creation, first of all, and then it leads to societal benefits. I still believe that wealth creation is fundamental because without generating novel processes and new ideas you are not going to create wealth and with that wealth you can bring a lot of social benefits, you bring education, you bring health and these sorts of things. But in addition to the fundamental wealth creation there are clearly things that bring society benefits and meets societal needs, and genetics is often the 'only' solution we have." ML, Programme Manager, Biotechnology, DGXII, CEC, Belgium

The funding of biotechnology is one of the few growing budget areas of the EU (K. Smith, 1996:101). Importantly, according to another CEC official, the main focus of CEC activities is on 'funding pre-competitive research'. The Bimolecular Engineering Programme (BEP) over the 1982-85 period was the first programme. With a budget of ECU 15 million, it aimed to encourage multinational efforts in research and training in the areas of molecular and cellular biology to agriculture and to agro-food industries. The second R&D programme (1985-89) was the Biotechnology Action Programme (BAP). With a budget of ECU 20 million, it aimed to encourage non-competitive research oriented towards medium- to long-term objectives. Following BAP, a third programme (1990-93) initiated by the CEC was the ECU 100 million Biotechnology Research for Innovation, Development and

[15] One of the outcomes of this in biotechnology was the production of a guide book 'Biotechnology in the Netherlands: The Network Approach' (MEA, 1994).

Growth in Europe (BRIDGE) programme. This aimed to consolidate developments achieved in the BAP. As a supplement to BRIDGE, the BIOTECH 1 programme endowed with ECU 189 million started some new areas of research. The current BIOTECH 2 programme with a budget of ECU 552 million covers four specific areas of activity aimed at encouraging research, training and development (RTD). In addition to these specific biotechnology oriented programmes, the CEC has developed a number of focused research programmes such as those on agro-industrial research. These also have encouraged RTD in biotechnology (Bongert, 1996). The evolution of the CEC sponsored biotechnology programmes has been anything but linear, but they have sought to establish Union-wide activities improving the competitiveness of laboratories whilst at the same time strengthening national programmes (Magnien and Nettancourt, 1993). Leaving aside the rationale and basis for such programmes (to encourage socio-economic cohesion across the Union), it is widely recognised that in Europe, there has been a failure to commercialise the 'world class' research in biotechnology emerging out of public funded initiatives (CEC, 1998b). Superficially, at least, there has been a shift recently in CEC funding on biotechnology; funding under Framework V is likely to see biotechnology programmes subsumed under a broader 'life sciences' category (CEC, 1996b; 1998c).

From the story above it would be wrong to assume that the importance of public funding of biotechnology is restricted to the innovation of enzyme Y. Whilst the role of the TNO is an obvious manifestation of the public funding of biotechnological innovation, according to the research manager for enzyme X, public money is seen to be crucial in terms of the 'training and supply of scientists and technologists and creating an environment that encourages R&D in biotechnology'. Perhaps the most obvious indicator of the importance of public funds for enzyme X is in the fact that firm A is situated in a government sponsored science park. As a research scientist notes, firm A moved to that location because of 'government subsidies'. Moreover, for both enzymes X and Y, European funds are also important as both sets of firms are involved in pan-European projects as part of a broader corporate strategy. Thus although not directly funded by the CEC, firms A, C and D have benefited from CEC funded projects; for example, firm D is currently involved in a CEC funded project on genome analysis.

One additional point emerging from the story above is the role of specific individuals in the promotion of biotechnology. For instance, in the Netherlands, one individual interviewed was identified by a number of interviewees as playing a critical role in raising the profile of biotechnology in the political arena. Similarly, in Denmark, the head of the scientific committee of the Danish parliament (Folketing) was personally interested in biotechnology because of his work at the university. He played an important role in ensuring that biotechnology had its own budget controlled by the Folketing. Thus whilst the role of public funding and institutions is considerable in the innovation of enzymes X and Y, in many instances it is down to the personal involvement of a number of individuals to direct the funding that is the crucial factor.

6.3.4 'No' to human cloning, 'yes' to GMEs: regulating (agro-food) biotechnology

Another issue involving public interests in biotechnological innovation centres on its regulation. The need to regulate the applications of agro-food biotechnology is linked to broader debates about risk in modern capitalist societies generally and its safety in particular (Berstein, 1995; Levidow, 1996; Rousch and Shelton, 1997; Walter, 1998). Safety issues in biotechnology are the subject of enormous public concern and date back as far as the Asilomar conference in the US in 1975 where the risks associated with rDNA technology were discussed (Cantley, 1995). This area of public concern is not straightforward (Deshayes, 1994:5). For instance, there is a debate around the limited 'scientific' analyses of risk assessments and the extent to which 'scientific (il)literacy' is important in influencing views on biotechnology (Dixon, 1995; Golub 1997). Added to this, as the recent cloning of animals highlights, the public generally is less comfortable with some developments in biotechnology (Hallman, 1996; Nielson, 1997).

The choice of *aspergillus* as the source of enzyme X has been partly influenced by issues to do with safety and public acceptance. In Denmark, concern over biotechnology became institutionalised during the early stages of the development of enzyme X. In 1986, the first law in the world on rDNA technology was passed regulating the use of such technology for humans (Terney, 1996). Essentially, this law

allowed two Danish companies Novo and Nordisk (which later merged into one) to produce human insulin expressed in yeast and human growth hormone expressed in *e coli.* For enzyme X, this law provided a specific legal basis for the use of rDNA technology in traditional fermentation techniques such as those used in the production of GMEs (Mahler, 1996). Therefore, whilst the 1986 law was seen to provide protection for consumers, it also sanctioned the use of rDNA technology for use in the manufacture of GMEs.

In 1991, Danish regulations were subsumed under European wide legislation (Terney, 1996:71). Regulatory developments at a European level assumed particular importance in the early stages of the innovation of enzyme Y in the Netherlands because they began to be developed and applied at this time (NFIA, 1995).[16] In broad terms, the regulatory framework for biotechnology had been previously discussed in terms of either process based regulation (e.g. the act of genetic modification) or controls over the final product (e.g. the plant that is actually grown and eaten), with the US taking the former and EU the latter approaches (Poole, 1996:72; Shotet, 1996). Two aspects of the European regulation became important. The first was directives 219 and 220 which provided the framework for contained use and environmental releases of GMOs. Directive 90/219/EEC covers all activities with genetically modified micro-organisms (GMMs) that take place in contained facilities, either for research purposes or industrial usage, distinguishing between groups of GMMs and types of activities according to the levels of risk involved. It bears on the research community in general and the pharmaceutical and food industries specifically. Directive 90/220/EEC encompasses all activities that intentionally take place outside contained facilities. It covers the environmental assessment of GMOs (micro-organisms, plants and animals) through all the stages of release into the environment (EP, 1994:38-39).

[16] The problems with regulating biotechnology at a national level mirror many of the issues at a European level. For instance, according to the head of biotechnology regulation at the CEC (DGIII), the CEC face a dilemma as two options are open to them on how to regulate a fast moving area such as biotechnology. The first is to make the rules very general, capable of taking into account any future developments; the second is to provide a more detailed brief for the regulations. Eventually, in the EU it was decided to adopt the first approach, with regulations of a rather general nature which need to be continually up-dated.

A more recent piece of European legislation important to agro-food biotechnology is the Novel Foods and Novel Food Ingredients Regulation 258/97 which came into effect on 15 May 1997 (Johnson, 1997a). The CEC proposed a pre-market system to examine the safety of foods that are truly novel either because they are changed significantly by new processing methods or because they are significantly different from foods currently available (Miller and Flamm, 1993). This piece of legislation pivots on the notion of 'substantial equivalence' whereby a food which is produced using rDNA technology, but is seen to be similar to that conventionally produced, would mean that existing systems of regulation would suffice (IFST, 1998).

Today, European-wide regulation is seen as very important for agro-food biotechnology, but much of this legislation came after the early stages of the innovation of enzymes X and Y (MANMF, 1995; Terney, 1996). Nevertheless, in both Denmark and the Netherlands, a national statutory system for regulating GMEs was in place early on in the development of rDNA technology and this roughly followed the 'substantial equivalence' line:[17]

> "...if you look at an enzyme as a chemical, we would usually look at what it is being used for compared to...the natural occurring enzyme. But basically I don't think we would consider an enzyme a GMO because I think if you manufacture an enzyme with the use of GMM as the sort of manufacturing animal, then we will say that to carry out the production in the fermentation you need the necessary approvals according to 219 directive because there would be contained use. But once you have carried out the purification steps and so on and end up with the enzyme as a chemical, a well defined chemical, that chemical is not a GMO...and consequently it does not need for 'production' purposes a separate approval...." AW, Director, Ministry of Environment, Denmark

In the UK, however, before being subsumed under European legislation, GMEs were regulated like other enzymes under the 1990 Food Safety Act (FAC, 1992). One MAFF official describes the situation:

> "Well the Food Advisory Committee has looked at its policies and provided that they've been cleared for safety first of all then it should be permitted...[By whom?] The ACNFP. And if there's nothing in the final product which makes it significantly different to conventional food that have enzymes in that particular case, then there's no obvious

[17] According to the head of the biotechnology division of the Danish Environmental Protection Agency (EPA), the Danish interpretation of the regulatory framework is pragmatic as it is based on 'qualified dialogue'. By contrast, according to the head of communication at the Danish Consumer Council (*Forbrugerradet*), the Government is considered 'too pragmatic' as industrial interests often take precedence over those of consumers. Paradoxically, the Danish Minister for industry is also in-charge of consumer affairs.

requirement to let the consumer know that this particular product has been made using a GME." CL, Committee Secretary, Food Advisory Committee, MAFF, UK

More fundamentally, unlike in Denmark and the Netherlands, the UK system works on a voluntary basis. The voluntary code for the regulation of GMEs is overseen by two independent non-statutory committees. The FAC advises the Government on the exercise of powers in the Food Safety Act 1990 relating to the labelling, composition and chemical safety of food (FAC, 1992). The ACNFP was set up in 1988 in light of the increasing importance of biotechnology, and it also advises the Government on matters relating to the irradiation of food or to the manufacture of novel foods or foods produced by novel processes (ACNFP, 1990). The voluntary nature of the regulation for GMEs, however, did not stop regulatory approval for enzyme X being sought in the UK and, after firm A submitted the initial dossier in 1990, it was finally approved in 1991 by the UK Government (ACNFP, 1991).[18]

But the story of the regulatory approval for enzyme Y in the UK is considerably more complex. Historically, bread in the UK has been a highly regulated commodity with special arrangements for enzyme preparations used in its production. Essentially, the 1984 Bread and Flour Regulations lay down a positive list of permitted additives; materials not on the list could not be used (Hammond, 1994). This meant that these were the only specific controls in the UK on the use of enzymes in food processing apart from those controlled as miscellaneous food additives (MAFF, 1996). The availability of enzyme preparations for use in bread making, then, was very restricted; although amylases and proteinases were permitted, hemicellulases such as enzyme Y were not. And yet given that hemicellulase preparations were permitted (and manufactured) in certain other EU states such as Denmark, Germany, the Netherlands and Spain, under the rules of the Single Act, products legally manufactured using hemicellulase preparations were freely entering the UK.[19] Added to this, another chemical oxidising

[18] In the UK, the first food product produced using rDNA technology sold to the public probably was cheese suitable for vegetarians. The Co-op, unlike the other major food retailers, in its 'Right to know campaign', labels its vegetarian cheese, 'Produced using gene technology and so free from animal rennet.' Further, it is interesting to note that most cheese labelled 'suitable for vegetarians' is produced using a GM chymosin. As an aside, the Co-op refused to stock products such as the purée made from GM tomatoes (*Times*, 1994). Another food retailer, Iceland (1998), have stopped using GM ingredients in their food products.

[19] As a matter of record, one development manager of a bread improving company suggests that hemicellulases were used illegally in the UK during this time. Whilst it is difficult to draw general conclusions from this simple observation, what seems certain is that the food

bread improver (potassium bromate) was banned in 1990 leading the baking industry to feel that hemicellulase was their only option for tackling their dough quality problems. They therefore began to think about how to get hemicellulase permitted. As one interviewee involved in getting hemicellulase permitted describes:[20]

> "...we made the case that hemicellulase should be added. They (FAC) had accepted the case of need; there had been a number of hemicellulase preparations that had been accepted by the committee on toxicity as safe for use in food, and the 1984 regulations were amended in 1995 by the addition of hemicellulase...it was a simple amendment that added hemicellulase to the schedule of the permitted additives....Very shortly afterwards we began to think crikey, what an enormous amount of effort had gone in to securing the authorisation of just one enzyme preparation hemicellulase....So we were beginning to think that we ought to make a case for abolishing specific controls on enzymes, and so when the draft regulations were issued... we argued for no controls on enzymes in bread other than the general controls of public safety, and we did that in a submission dated November 1995....That then led to proposals in early 1996 for bread and flour regulations....And it basically deleted the specific enzymes and amended the definition of flour treatment agents in such a way that it was possible to use enzymes freely in bread and flour...."JH, Secretary, Food Trade Organisation, UK

Hemicellulases, and enzyme Y more specifically, played an important role in encouraging the deregulation of food ingredients and processing aids in the UK. In fact according to the FAC (1996), it is now accepted that there is no evidence to suggest that enzyme preparations used in bread (and cheese) present a greater risk than those used in the manufacture of other types of foods. In recognition of this it was recommended that the positive list (a list of enzymes that could be used) for bread baking enzymes be removed and that hemicellulase would only be subject to the general provisions of the Food Safety Act.

The regulatory story of biotechnological innovation described above highlights a number of processes and issues. As well as highlighting obvious differences between consumer and industrial interests, the regulatory story shows the potential rivalry between national governments and European institutions (Hodgson, 1997c; *Nature biotechnology*, 1997b). What is more, within the European context of regulation of biotechnology there have been some fierce debates; for

---

system is a difficult area to regulate because of the considerable number of inputs and processes being employed.

[20] Whilst GMEs are seen as commodities largely influenced by price, hemicellulases hold a slightly strange position because they are felt by a number of interviewees to hold out the prospect of solving some of the major problems faced by bakers. That said, one product manager in firm C is of the opinion that although price is important, hemicellulases are slowly being 'demythologised' and becoming another commodity item to be sold on price.

instance, within the CEC between DG VI (agriculture) and DG XII (R&D) over supporting research in biotechnology where this would affect agricultural interests.[21] More specifically, it is clear in the innovation of enzymes X and Y there are contradictions and ambiguities over the importance of regulation between interests and actors. As a spokesperson for the Danish biotechnology industry points out, 'whilst initially we felt that a specific law was unnecessary for biotechnology it later had advantages as it appeared to sanction biotechnology and reassure the public'. In the UK, according to one manager in a bread improver company, it is 'the bread baking industry that found it important to get hemicellulase permitted, the enzyme manufacturers were not that interested'. The varying impact of regulation on the innovation of enzymes X and Y is not restricted to Europe. Enzyme X took over ten years to develop because (partly) of the length of time it took to get approval from the Food and Drug Administration (FDA) in the US and reflected both the importance of the US market for the sale of coagulants and the involvement of firm B. In a general sense, then, there is a great deal of overlapping of interests and activities in the regulatory story.[22]

6.3.5 Read the label stupid!: informing the public about biotechnology

Another dimension to the regulation of enzymes X and Y centres on labelling (FDF, 1996b; Grove-White, 1997; IGD, 1997). In this matter, as the recent decision in the UK to ban the use of GM soya by the food retailer Iceland (1998) testifies, the role of retailers is pivotal. In many instances, the food retailers inform consumers about

[21] An obvious example of a conflict of interests in agro-food biotechnology is that the DG VI responsible for agriculture would not want agricultural production to increase through new technologies as this would increase the pressure of paying subsidies. According to one person at the CEC this conflict of interests was especially acute with research on bio-fuels which encourages the increased production of oil seeds.

[22] To compound matters, at the time of the innovation of enzyme X there was little agreement between the US and the Europeans on the regulation of GMEs and biotechnology more generally. Recently, however, a mutual recognition agreement (MRA) to ease the international trade of approved drug and biological products has been concluded (Fox, 1997a). The main focus of the MRA is to assure regulatory officials that facilities used by manufacturers on one side of the Atlantic meet the good manufacturing practices (GMPs) insisted upon by their counterparts from the opposite side. How this will affect GMEs is hard to assess since the agreement has been developed with the drug industries in mind. Nevertheless, it is conceivable that if progress is made in the health sector it may translate to agro-food biotechnology.

biotechnology (IGD, 1997). Despite the reluctance to accept GM foods among consumers (FDF, 1996a), there is a general feeling among industrial interests that given these developments are taking place, consumers should be given information which allow them to make informed choices (Hansen, 1991; Hatch, 1996). Given this, the CEC has published labelling rules for GM food products. These cover all foods containing GM ingredients and which 'must' be labelled that they contain GM constituents; foods that 'may' contain GM ingredients must have labels saying that they 'may' contain GM constituents; and foods that do not contain such ingredients can be labelled 'free' of GM ingredients (Michael, 1997).

In both Denmark and the Netherlands, the labelling issue is linked to a wider public debate from the late 1970s about biotechnology (PWT, 1996; Terney, 1996), and in both countries the public appear well informed about matters relating to biotechnology (CEC, 1997a). Unlike the German public, who also have a high level of understanding, knowledge and information on biotechnology, knowledge does not translate into scepticism. Both the Danish and Dutch publics are positive and optimistic about developments in certain areas of biotechnology. In Denmark, for instance, this optimism is linked to the 'openness' of the 'Danish model' as reflected in consensus conferences (Mahler, 1996). Although originally developed in the US, the Danish Board of Technology adopted the consensus conference in the 1980s to describe a new form of technology assessment involving a panel of lay people covering topics, such as transgenic animals, irradiation of food, and more recently, plant genetics (NCCPB, 1994:4; Terney, 1996).[23] Emerging out of these consensus conferences and wider debates in Denmark was a clear sense of a need to label GM foods and ingredients (Teknologi-Rådet, 1995). In the Netherlands, the reasoning behind labelling was equally simple. As the project manager for the largest consumer organisation in the Netherlands remarks, 'consumers have the

[23] Increasingly, this method is being adopted elsewhere; for instance, in the UK a consensus conference was held in November 1994 to consider plant biotechnology (NCCPB, 1994). Importantly, consensus conferences are influenced by the widely held belief that the public is largely ignorant of science (and technology) and therefore a greater 'public understanding of science' is required (see, from amoung many examples, Durant 1992; Wynne, 1992; Macintyre, 1995, Eden 1996). Whilst I agree that technoscience is a critical aspect of modern society, it is interesting that the need to educate the public on such matters has become such a major academic and political project, when as Kealey (1996:346-347) points out, the legal system impacts as much on our day-to-day lives as does technoscience and yet there has been little attempt to have a 'public understanding of law'.

right to know what they are buying, they must have the right to choose'. In the Netherlands, the MEA suggest a labelling policy for biotechnology based upon consultation with all interests because, according to one of the main facilitators of this process:

> "...biotechnology is a difficult issue in Europe and also in Holland and they (MEA) were hoping...that it would be a very interesting new technology and very important for Holland which is traditionally strong in that field. But they also saw some problem arising with the acceptance in society, so they said we don't want to push biotechnology and make that statement but we want...we like that it became an important technology. So how do we communicate in this difficult field?" KB, Consultant, Communication and Information Consultancy, The Netherlands

Following discussions at the MEA, a consultation group was set up in 1993 to consider how to communicate biotechnology. Members of the Communication Consulting Group on Biotechnology (CCGB) covered a range of interests involved in biotechnology - from industry to consumer organisations[24] - and met every two months to discuss problems and strategies of communicating biotechnological products to the public which were near to market introduction. Despite diverging opinions about labelling, the Group was seen to provide a constructive forum for the exchange of ideas. In the case of GMEs the discussions proved important for industrial interests as it was agreed that labelling was unnecessary. Generally, though, in the Netherlands industrial interests are not against the labelling of biotechnology. As a director of a biotechnology trade organisation represented at the Group remarks, 'industry was not against this idea but it should be workable and realistic legislation'. Interestingly, one of the members of the Group was involved in the innovation of enzyme Y.

The labelling issue in the UK is more contested and reflects a greater conflict of interests between actors. Typically the industrial point of view is as follows:

> "I don't wish to take a view which actually prevents the consumer from having full details and knowledge of what they're buying. But conversely it is a pretty impossible task." DG, Technical Executive, Food Retailer, UK

[24] The members of the groups included representatives from industry, government and trade associations. Also represented were the *Publieksvoorlichting over Wetenschap en Teckniek* (PWT) a foundation for Public Information on Science and Technology funded by the MEA. Established in 1990 when biotechnology began to be discussed in the public domain, it aims to inform and educate the public on matters to do with biotechnology.

Despite the move by some retailers (such as the Co-op and Iceland) to label certain GM goods, overall, industrial concerns are reluctant to label such products mainly because of the belief that consumers in the UK are not willing to accept the interference of food by rDNA technology (FDF, 1996a; CEC, 1997a). It is felt by industrial interests that too much information deters consumers. Given this view, and the increased internationalisation of the market for many of products, attempting to find a standard labelling procedure for different countries is proving extraordinarily difficult. In the UK, the labelling of biotechnology is discussed in a number of fora (IGD, 1997), where clear differences of opinion are expressed. Consumer groups insist on maximising choice and information, while industrial interests see information as having a negative impact upon sales and product development. One of the most contentious issues, brought about in part by the emergence of Bovine Spongiform Encephalopathy (BSE), centres on 'segregation' and 'traceability' as many of the agro-food multinationals involved in applying rDNA technology are resisting calls for segregation which have made the tracing of raw materials more difficult. Despite the increased importance and connection over the labelling issue in the UK, the labelling of enzymes X and Y is not required by legislation in the UK because they are GMEs.

Underlying the issue of labelling are the means by which the various interests are represented. According to the Head of Communications at a Dutch consumer organisation 'European institutions like the CEC are getting more power and we think it is important to lobby them'. At a European level, consumer interests are represented by the European consumer organisation, *Bureau European des Unions des Consommateurs* (BEUC).[25] In the main, its interest in biotechnology has been in legislation and ensuring that as much labelling as possible characterises the biotechnology field. Representing industrial interests at a European level, several groups - the Senior Advisory Group on Biotechnology (SAGB), the European Secretariat of National Bioindustry Associations (ESNBA), and the Association of Microbial Food Enzyme Producers (AMFEP) - are seen as especially relevant for enzymes X and Y.[26] Whilst the strategies adopted by consumer

[25] BEUC was set up in the early 1960s. It is a Brussels based federation of independent national consumers organisations from all member states of the EU and from other European countries (BEUC, 1996). It aims to influence EU policy at all levels through creating effective communication lines with the main institutions, and by establishing formal institutions with the CEC such as the Consumers' Consultative Council (CCC).

[26] The SAGB was set up in 1989 as a response to activities that were starting to occur in European institutions that concerned biotechnology and represented some of the largest organisations involved in biotechnology, such as Novo Nordisk, Monsanto, Bayer, Hoechst,

and industrial interests are seen to be quite different - Parliament is seen to be more sympathetic to consumer concerns; the Commission and Council tend to focus more on the interests of industry[27] - both aim to influence the regulatory and legislative environments and the funding and the direction of research.[28]

For the innovation of enzymes X and Y, the labelling debate has several important implications. Above all, the issue around whether and what to label highlights the possible shift in power in the agro-food system. One food retailing executive in the UK has noticed 'a discernible shift in power down-stream away from the food retailers to the large agro-chemical conglomerates'. Why exactly this shift may be happening is open to question, but it can be linked to the increased concentration of interests in agriculture in a few large companies.[29] For enzymes X and Y, the labelling issue proved to be a minor issue, but one that could not be totally neglected. As a representative from the biotechnology industry association points out, 'public acceptance is of crucial importance, at least in the short term, but it is only a small part of the regulation that may have an impact on product delivery'. More speculatively, the arguments for not labelling GMEs because of the 'substantial equivalent' argument seem to have paved the way for a broader move away from labelling. Thus despite fundamental differences towards labelling between countries - for instance, whilst the US seems more eager to see GM foods globally distributed without special labels, in Europe there is a sense that some form of product labelling is

---

Hoffman La Roche, Rhone Polenc, Zeneca, British Biotech, Ciba Geigy, Sandoz, Nestle, and Unilever, representing a cross-section of interests in the agro-food system. By contrast, the ESNBA was seen to represent smaller and medium sized companies. But since 1996 these two bodies have merged because of a synergy in terms of the issues at hand. Representing over 500 companies, Europabio is said to reflect a turning point in lobbying European institutions (Europabio, 1996), although it is suggested that their 'voice' is dominated by former SAGB members (*Nature biotechnology*, 1997c). The AMFEP was established in 1977 to provide a common basis for representing the interests of enzyme manufacturers in negotiations with the CEC and other national and international organisations. In addition, it has sought to inform members about developments relating to the regulatory status of food enzymes (AMFEP, 1990). It is worth pointing out that many members of AMFEP (such as Novo Nordisk and Gist-brocades) are also members of Europabio.

[27] One of the most important shifts at a European level that has influenced the nature of lobbying is the increase in power of the EP. It is felt by some lobbyists that greater attention has to be focused on the EP. Additionally, it is suggested that applying pressure at a national level helps promote interests at a European level.

[28] For a general introduction to biotechnology lobbying activities in Europe, see Greenwood and Ronit (1994).

[29] The US multinational company Monsanto is a good example of this concentration of interests as it is aggressively increasingly its control on the raw material and seed market (*Nature biotechnology*, 1998c).

required (Fox, 1997b) - there are signs that the removal of labelling of GM foods is gaining momentum as in Japan (*Nature biotechnology*, 1998b) and New Zealand (Hodgson, 1997c). This shift started with the deregulation of GMEs.

6.3.6 We also need protection!: patenting GMEs and intellectual property rights

Patenting, and IPR generally, are considered to be crucial for biotechnological innovation as they are seen to protect and, therefore, to encourage innovation (Jorritsma 1993, Arthur Andersen, 1994, 1997; NABC, 1995; Ernst & Young, 1996, 1998). The issue of patenting biological matter first emerged in 1980 in the US with the Diamond vs Chakrabarty case. The Supreme Court held that a live human-made micro-organism was a patentable subject (Kevles, 1994). Patents are granted according to whether an invention is 'novel', if it is not previously described, or 'nonobvious' (if the invention is not an obvious next step during the process) (Johnson, 1997b). Of course, patenting is no guarantee that another company will not steal your ideas; for instance, in the US the pharmaceutical company Hoechst is currently fighting a multi-million dollar law suit filed by the DBF Amgen over the infringement of the drug erythropoeietin (*Nature biotechnology*, 1997d). Patenting and intellectual property are elusive concepts as even when a patent is granted it is still open to challenge (*Nature biotechnology*, 1997e).

The patenting issue is seen to influence the considerable length of time it took to develop and produce enzyme X. As the research secretary in firm A notes:

> "...the critical steps in the development of...enzyme X were already in the cloning process. So already at that stage there was patentable matter and that was back in the early 80s....And then there have been a lot of patenting activity at a later stage when the product was emerging...was developed, I mean the purification, even the method for killing the production of an agent was patent protected...that happened in the late 80s....I mean it is the first major innovation there has been in this area since 1874 when industrial production of rennet started...there have been some improvements from time to time, but nothing really major, until...the gene technology." JS, Research Secretary, Firm A, Denmark

The value of applying rDNA technology to the innovation of enzymes is highlighted by the need to protect the work. Despite strong calls for IPR to protect

inventions and, by extension, encourage innovation, the reasons behind patenting are complex and varied:

> "It could be done for prestige reasons....You can use it for local or specific coverage of your invention. But you can also use it in order to pave the whole area to make it difficult for others to operate in it...you can sort of make...broad claims...that prevent others from patenting more specific developments within that area...." JS, Research Secretary, Firm A, Denmark

A balance has to be struck between patenting costs, the need for protection, and also the desire to maintain some secrecy. For enzyme X, though, the case for patenting was clear given that for firm A it was an entirely new way of producing chymosin and the potential profits were large. Added to this, the investment involved in the innovation of enzyme X was considerable and, therefore, there was concern about protecting investments. But this raised the issue of where to apply for the patent.[30] As there is no such thing as a world patent nor World Patenting Office (Johnson, 1997b), for enzyme X, the European Patent Office (EPO) was considered the most obvious place to apply for a patent. At the time, patents issued through the EPO in Munich provided a route to intellectual property protection across Europe; but the absence of a unified system for prosecuting those patents was seen to weaken the position of patent holders (Ward, 1997). The CEC, therefore, felt that without common legislation, EU research and exploitation of its results would be discouraged and placed at a disadvantage with competitors outside the EU (ibid.). Thus whilst enzyme X was being patented, the issue of the need for harmonisation across the EU became prominent in terms of bringing in protection for biotechnological and/or 'living' inventions. In October 1988, the CEC proposed a draft Directive in response to complaints from European industry over the lack of clarity of patent law to address the patent laws problems of biotechnology as whole (Crespi, 1995:162). In 1995, the CEC put forward a new directive designed to harmonise national patent law, and aimed to ensure that no invention would be refused patent protection for the sole reasons that biological material was involved (ibid.).[31] But after discussion and rewrites, the proposal was rejected on 1 March 1995 by the EP (*Independent*, 1995a).[32] Nevertheless, a new draft was

[30] Patents are generally not written by lawyers but by scientists and engineers in patent agencies. In the case of enzyme X a patent agency based in London was used.

[31] The parameters of this legislation included the patentability of biological material; the scope of protection; the distinction between a discovery which is non-patentable and an invention which is; and exclusions from patentability such as germ-line gene therapy (SAGB, 1996a).

[32] According to the Director of the most important European biotechnology trade lobby, this was due largely to two factors. First, the industry did not take into account the importance of the EP

put together which made it clear that biological material and human genes were patentable and which has a reasonable chance of getting through (Ernst & Young, 1996:50; Ward, 1997).

For the innovation of enzymes X and Y, patenting and IPR are connected to a broader political-economic framework which influenced how they came about. In the main, the IPR related to biotechnology are linked to broader changes in the multilateral trading system, especially those connected to WTO agreements and the Codex Alimentarius. For the WTO, two aspects are important. The first relates to the Trade-Related Intellectual Property Rights (TRIPs) provision of the GATT, signed by 115 nations in April 1994. Section 5, Article 27 of TRIPs states that 'patents shall be available and patent rights enjoyable without discrimination as to the place of invention, the field of technology and whether products are imported or locally produced' (WIPO, 1996:31). But in the area of biotechnology, agreements on TRIPs and intellectual property prove difficult because:

> "... the matter is probably, I say probably because it is...up to national law, it is probably not yet right for a complete generalised solution....They have different views and there are hesitations. In many cases...on the scope of the protection that should be granted. Still it is boiling and it will ultimately reach a conclusion but not today." AI, Communications Director, WIPO, Switzerland

Notwithstanding the failure to achieve a consensus, the need to reconcile national differences with international requirements is clearly important to bodies such as the WIPO.[33] But for enzyme X, a more important aspect of international trade regimes centres on the Technical Barriers to Trade (TBT) and Sanitary (human and animal health) and Phytosanitary Measures (plant health) (SPS) (WTO, 1994, 1996). These two measures are designed to prevent technical legislation which is intended for the protection of the human health or safety, the protection of the heath and life of human,

---

and the dynamics of how European political systems and institutions (Commission, Council and Parliament) worked. Second, the patent lawyers used to inform the Parliament were considered the wrong kind of messengers as the messages were too technical.

[33] The WIPO's role is essentially normative in that it is set tasks from its members (nation-states) to look at issues to do with intellectual property and copy right. For biotechnology, a procedural (rather than normative) treaty administered by WIPO, the Budapest Treaty on the International Recognition of the Deposit of Micro-organisms for the Purpose of Patent Procedure, has been in effect since the 1970s. This treaty aims to simplify the procedure for filing for a patent by allowing just one deposit of the original micro-organism to suffice for all countries.

animals or plants, consumer protection against deceptive practices and environmental protection being used to create unjustified barriers to international trade (CEC, 1997b:58).[34] Thus for enzyme X, the concern was whether a country would be allowed to block the import of GMEs on the grounds of safety and health.[35]

The TBT and SPS rules are based on an assessment of risks to health that take into account available scientific evidence. The basic scientific evidence on biotechnology for multilateral trade agreements is generally provided by the Codex standard.[36] The FAO and WHO set up a joint committee on the Codex Alimentarius in 1962 to prepare standards, recommendations and guidelines with a view to protect consumers' health, ensuring fair trade practices and facilitating international trade (CEC, 1997b:60). Within the Codex standard, GMEs such as enzymes X or Y, are dealt with by the Joint Expert Committee on Food Additives (JEFCA). JEFCA is responsible for preparing scientific assessments of hazards which form the scientific basis for the preparation of Codex standards (ibid.:61), and works towards the harmonisation of rules. But in dealing with scientific assessments of safety, both Codex, and to some extent JEFCA, have an ambiguous role. As a Codex official describes:

> " [Codex]...is not purely scientific, there are scientific aspects it should be based on science when food safety is concerned, but there are some aspects taken into account like labelling, it depends on the policy. And we also have a committee on nutrition and we

[34] The importance of trade-environment issues only emerged right at the end of the enzyme X's technological trajectory. According to one WTO official, the catalyst for environmental issues was the 1991 tuna-dolphin dispute where a GATT panel ruled against the US saying it was acting in a discriminatory fashion against countries that did not use specified fishing nets. Thenceforth, the main focus has been whether environmental policies create distortions to trade (not whether trade has environmental consequences). Unfortunately as one UNEP official notes, 'everything now tends to be trade related and the separation of environmental and trade issues is impossible at an international trade level'.

[35] In addition, trade related environmental measures (TREMs) have been applied to various multilateral agreements (MEAs) (Ingrassia, 1996). These refer to trade measures which aim to protect the environment. For instance, trade restrictions or standards, such as labelling, could be applied to biotechnology to protect the environment or human health (ibid.:5). As far as GATT/WTO rules are concerned, biosafety regulations have not been challenged under them. Nevertheless, under the SPS agreement no country is prevented under WTO rules from adopting or enforcing measures necessary to protect human, animal or plant life or health, as long as they are not applied in a 'arbitrary or unjustifiable' way (WTO, 1994). Therefore, the SPS can provide health protection as well ensure rights are not misused for protection purposes (WTO, 1996). Having said that, it is important to consider whether these agreements are neutral as there is strong evidence to suggest that they favour certain countries particularly industrialised ones where much of the innovation in biotechnology occurs (see, for example, Junne and Wijk van, 1992).

[36] The 'seal of approval' from Codex is also used as a marketing tool by enzyme manufacturers.

try to get a consensus. And also the trade aspects and quality which is more related to trade, so we try to get a consensus." SD, Food Standards Officer, Codex, Italy

Codex witnesses a tension between national and international standards and when scientific evidence is in question it is difficult to arrive at a consensus. For enzymes X and Y, the interrelationship between 'scientific' and 'political' aspects is especially relevant given that they were among the first food grade GMEs to be developed and used. There are, however, numerous influences on the scientific assessments of safety of GMEs including industrial interests. For enzyme X, for instance, the International Dairy Federation (IDF) played a key role in achieving consensus amongst its members and increasing the acceptance of GMEs through its programme of work on the use of GME preparations used in the manufacture of cheese (IDF, 1996:9).[37] Interestingly, firm A was involved extensively in the work of the IDF on GMEs.

The story weaved around the innovation of enzymes X and Y points to the importance of patenting and IPR for biotechnological innovation, although direct references to patenting and IPR only emerged in the investigation of enzyme X. In part this is due to the considered novelty of the application of rDNA technology to the production of food grade enzymes. In addition, firm A considered itself to be less secure in the market and wanted to protect its investments. Of course enzyme Y was patented, but unlike enzyme X, the patent was more narrowly defined as it concentrated on the cloned material and reflected other developments that had taken place in the hemicellulase sector. In addition, firms C and D are seen to have considerable resources dedicated to IPR; that is, IPR is treated as a routine aspect of innovation. Interestingly, the number of patent applications for biotechnology considered by the US Patent and Trademark Office in the US dropped by 55 percent between 1995 and 1997. According to Steinberg (1997b), this drop is influenced by two factors. Firstly, the new GATT/WTO rules which went into effect in June 1995 shortened the life of a patent. Secondly, the development of the biotechnology patenting process leads to the increased efficiency of drafting patent cases. International trade developments

[37] The IDF is an independent non-profit association based in Brussels. It promotes developments in dairying by encouraging analysis, by representing the dairy industry, consultation and advising, and by acting as a forum. Its main role is to co-operate with international organisations like Codex to facilitate trade in milk products and guarantee their quality. It has 37 member countries.

in which patenting has figured strongly also remain important as the recent entry of GM maize from the US to the EU illustrates (Fox, 1998; Hodgson, 1998). But what is apparent, and reflected in the different attitudes towards the innovation of enzymes X and Y, is that the application of rDNA technology to the manufacture of enzymes is more established than in other areas using these technologies.

6.3.7 Make or buy?: piloting, producing and marketing GMEs

The patenting of GMEs is not the only element of innovation that has an international dimension; the production of enzymes also involves a series of complex international relations and agreements. There is a growing consensus on the global exploitation of science and technology and the increased international collaboration that is associated with multinational corporations (Patel and Pavitt, 1994). Whilst there remains considerable debate over the balance between national and global forces that are important to technological innovation (see, for instance, Lundvall, 1992; Amin and Thrift, 1997; Simmie, 1997a, 1997b), global patterns, such as the acceleration of foreign direct investment, the growth of intra-industrial trade, the international movements of skilled personnel, and the liberalisation of capital and foreign exchange markets, all contribute to technological innovation (K. Smith, 1996:118). Specifically, arrangements linking large pharmaceutical companies with smaller DBFs (*Financial Times*, 1995; Kenney, 1995), and the role of international organisations in promoting biotechnology (Zilinskas, 1995), inevitably mean that biotechnological innovation is increasingly global in character.[38]

The international aspects of the innovation of GMEs is already apparent from this research. The cloning of enzyme X was undertaken by a US firm (firm B). A second international aspect of the innovation of enzyme X emerged when the laboratory developments needed to be scaled-up to production. Firm A did not have sufficiently large fermenters to up-scale production and, therefore, it was left to firm B in the US to undertake the piloting. Moreover, when it came to producing enzyme X, firm B also undertook initial production as it was seen as more cost effective than to

[38] A case in point is the HGP initiated in 1989 (started in 1991) and involving laboratories in over 15 countries (Balmer, 1996; Kevles, 1997).

construct a specific production facility elsewhere. As a production director in firm A remarks, 'we wanted to get a start in the production of enzyme X and it was the only reason why we co-operated'. Subsequently, production was later shifted to other facilities of firm B in Finland. In both instances, the unstandardised GM chymosin was sent to Denmark to be 'finished off' according to specific strengths and microbial activities. The renting of space in fermenters is one of the crucial aspects of the production of enzyme X. This decision was succinctly described by one director:

> "there's a lot of 'toll' manufacturing going on now....you get centres of fermentation expertise and you go along with your particular bug or whatever and say 'make this work for us', here's the production parameters, and you will rent out time. I think it's been going on in the pharmaceutical industry for years....But you know, the technology and all the stainless steel costs and whatever is so great, and there's manufacturing capacity around.....why not use it." BC, Director, Firm A, UK

The availability of facilities is an important characteristic of the production of enzyme X.[39]

The scaling-up of enzyme Y also posed problems for firms C and D. When developments were taken from the laboratory and tested out in production, strains often did not work and had to be abandoned. Unlike enzyme X, the piloting of enzyme Y was undertaken in a specialist pilot plant built by firms C and D which, according to its director, aims 'to shorten the innovation cycle'. The piloting of enzyme Y went relatively smoothly. When it came to manufacturing it, however, whilst the specialist pilot plant had production capabilities it was decided that larger facilities had to be used to maximise the potential. Two options were open to firms C and D. The first was to adopt a similar strategy to firm A in the innovation of enzyme X and get involved in a joint venture. As most of the hard work - the cloning and piloting of enzyme Y, for instance - had already been achieved, it was felt that a second option, the contracting out of production to a third party was preferable. But this led to a problem of secrecy as unlike a joint venture where information, resources and, of course, benefits are

[39] According to a production manager in firm A, the enzyme industry has been experiencing considerable movement with firms buying and selling to each other. For instance, Unilever recently sold its speciality chemicals division to Imperial Chemical Industries for £4.9 billion. This was to allow Unilever to accelerate its drive into developing markets (*Financial Times*, 1997c). More recently, the chemicals firm DSM has made a $1.4 billion acquisition of Gist-brocades (*Nature biotechnology*, 1998b).

generally shared equally, the contracting out of production to other enzyme manufacturers raised the possibility of information, knowledge and ideas being stolen. As one business development manager in firm C points out 'whilst a patent had been taken out on enzyme Y this is no guarantee that when the formulae are given to the producer's agents they would not copy or develop the samples'.[40] To prevent this, a particular strategy was adopted:

> "We just let's say...no I'm not going to tell you....But it means that your briefing to your enzyme producers...is a very poor one. Because if I would get such a brief from my customers today I most probably would have a major problem. So because we gave a poor briefing, the poor guy sent us 25 different samples something like that, and from that we selected one...the best one." HM, Market Development Manager, Firm C, The Netherlands

A broad and sketchy brief was provided to third party 'toll' manufacturers from which they were expected to produce strains and then manufacture them.[41] The main organisational strategy for the production of enzyme Y revolved around one issue:

> "Let's say with our company, 'make or buy' is always a very important decision. We make a lot of products and we buy some as well. And that is an on-going debate in this company and I guess in every company." DW, Business Unit Manager, Firm C, The Netherlands

Initially, the only option open to firms C and D was to rent out fermenters of a rival enzyme manufacturer in the Netherlands. Firm D later acquired a production plant in the Republic of Ireland which allowed it to take full control of production. This highlighted a move towards vertical integration and achieving greater control of the entire innovation process.

The decision to 'make or buy' a GME is a distinguishing feature between the innovation of enzymes X and Y. In the case of enzyme X, the manufacture of enzymes is seen as a core business and whilst initially firm A did not have the necessary expertise and facilities to undertake the innovation of enzyme X, taking control of the entire process is seen as necessary. For firm D on the other hand, the acquisition of firm C is seen to be part of a broader strategy of vertical integration

[40] Ironically, the research manager for enzyme Y moved onto a rival company.
[41] This was cross-referenced by the buying department of firm D, which as a large multinational company that also bought in enzymes, could obtain information about developments in enzymes from other GME manufacturers.

and controlling all the elements of the food provision cycle. Nevertheless, the production of enzymes is not considered a core business and, therefore, they are quite willing to buy in enzymes from other manufacturers if the innovation costs are considered to be too high. Interestingly, this strategy is further supported as firm D eventually sold firm C devolving its activities in the innovation of GMEs.

6.4 Discussion

The seven stories presented above reflect aspects of the network of biotechnological innovation. In **Figure 6.1**[42], a representation of the messy reality of how these aspects link into each other is given. In schematic terms, the use of the analytical framework has allowed a far more complex picture of biotechnological innovation to be discovered than would perhaps have been possible if current models of innovation were adopted (see **Section 2.2**) Not all the possible elements of the network of biotechnological innovation are identified; for instance, aspects associated with the raising of funds to support research in biotechnology, and the systems for writing patents for biological organisms, are neglected. In the main, the neglect of certain aspects of biotechnological innovation is influenced by the constraints of resources and time in this research project.

Many specific points of interest come out of the empirical findings. Take for instance the role of in-house expertise in firm A as a dynamic for innovation, or the role of charismatic individuals in promoting an innovation milieu in the Netherlands as seen in the innovation of enzyme Y. For this thesis, however, it is more useful to make a number of more general points about the nature and characteristics of biotechnological innovation? Eleven points can be made. First, the sources of biotechnological innovation are both functional and circumstantial. They are functional in the sense that the firms involved in biotechnological innovation systematically seek to innovate. In the case of enzyme X, the source of innovation in firm A emerged from a combination of its own internal innovation function and the influence of competitors and rival industries,

[42] Biotechnological innovation is so complicated that putting together a diagram to highlight all the decisions and actors was practically impossible. For the purposes of exposition, **Figure 6.1** shows some of the links between individuals interviewed during the fieldwork. The numbers in parentheses correspond to the interview number (see **Appendix D**).

and was seen as part of the firm's survival strategy in a highly competitive market. By contrast, circumstantial conditions in biotechnological innovation, which influence where and when an innovation comes about are also important. Although enzyme Y emerged from a planned strategy for innovation in firms C and D, a key circumstantial breakthrough was the discovery that a particular combination of enzymes had a desired effect on a bread baking system. This discovery led to the search for enzyme Y.

Second, the cumulative aspects of biotechnological innovation, and the importance of both incremental and radical innovations, are identified. Incrementally, the improved ability to clone host organisms for the manufacture of GMEs is shown in the shortening of time it took to clone the host organism for enzyme Y than for enzyme X. At the same time, radical innovations, through the general application of rDNA technology to the manufacture of enzymes which allows more desirable enzymes to be produced, are also pivotal for innovation. Biotechnological innovation exhibits both of these types of innovation, through which it shows a 'creative destruction' tendency. For example, whilst the adoption of rDNA technology is fairly slow in enzyme manufacturing, it is making enzymes produced using non-rDNA technology obsolete. Overall, however, the picture of innovation of GMEs is of incremental developments with short-term aims, such as in the improvement in the design of fermenters. Importantly, given that biotechnological innovation shows both incremental and radical tendencies, the process exhibits a cumulative tendency, one that takes place both in terms of design and object developments as well as a more general accumulation of knowledge (see **Chapter 7**).

Third, biotechnological innovation extends beyond the borders of individual laboratories and firms as a range of other actors and activities are important. Firms A, B, C and D, and certain individuals within them, play a central role in the strategy and management of the innovation of enzymes X and Y. But there are many other actors that influence the developmental trajectories of enzymes X and Y. In the case of enzyme X, for example, the Danish government has an important position in providing an environment that is conducive to biotechnological innovation. This is apparent in some of the reasons why the Government is involved in innovation, and the policies they develop, such as the first gene law, impact upon the strategy and decisions of firms involved in biotechnology. Similarly, for enzyme Y, the public nature of much of the

knowledge emerging from the innovation process is a critical factor in permitting public institutions, such as the TNO, to participate easily in the innovation process. The importance of this point, however, is not to confine the nature of biotechnological innovation to the activities of, and within, firms. Rather, it questions the dominance of focusing on inter-/intra-firm activity and makes more explicit the point of a more widespread and disparate 'innovation milieu'.

Fourth, there are tendencies towards both geographical centralisation and spatial dispersion in biotechnological innovation. For example, the relative small size of Denmark and the Netherlands seems to encourage greater co-operation between and amongst actors in the public and private sectors; in fact, this co-operation is frequently considered a primary objective for government sponsored programmes. In the case of enzyme X, the initial search for a partner to clone enzyme X took place in Denmark, and it was only after a suitable partner could not be found that firm B in the US was approached. But equally, there is pressure for spatial dispersion. This is most evident during 'production' as both enzymes X and Y are produced (or have been) in national contexts outside of the main R&D activities. Superficially, these two processes point to a degree of organisational flexibility associated with biotechnological innovation, and may lead to the emergence of new organisational arrangements. More pointedly, it is important to stress that the redefinition of many of these organisational arrangements reflects the existence of a more flexible basis to biotechnological innovation. Such flexibility is encouraged further by the growing importance of international regulatory mechanisms - tougher measures on the release of GMOs in the EU compared with the US, for instance - which lead to decisions on innovation having to take into account developments beyond nation-state boundaries.

Fifth, within the re-defined spaces of innovation, the re-definition of public-private relations is important. In the regulatory environment, for instance, the need to create new synergies between public and private interests involved in biotechnological innovation is identified, displaying a complex set of both 'top-down' and 'bottom-up' tendencies. For example, the creation of the first gene law in Denmark was initiated by the Danish government in an attempt to permit the development and use of rDNA technology in the production of human insulin by Danish companies and also to reassure the Danish public that the products from rDNA technology are safe. By

contrast, the debate and controversy over the labelling of GM foods emerges from a more disparate collection of sources, such as local consumer bodies, which in turn influence the regulatory process. These seemingly opposite tendencies underlie tension and uncertainty associated with public-private relations in biotechnological innovation and reflect further the complexity and ambiguity of biotechnological innovation.

Sixth, some sort of critical mass is emerging in biotechnological innovation whereby technological problems or weak or absent capabilities are being catered for and which point to the maturation, albeit slow, of the biotechnology sector. Whilst this critical mass may not necessarily be associated with fixed structures or clusters, networks of actors can be seen to be interacting in biotechnological innovation for the specific purpose of the development and application of this technology. A case in point is the need to combine expertise in rDNA technology for cloning with more general production and fermentation techniques in the innovation of both enzymes X and Y, and this led to particular institutional arrangements being established. These links between otherwise disconnected actors aim to compensate for weak expertise in rDNA technology and, increasingly, are becoming a more permanent feature of biotechnological innovation.

Seventh, the actors involved in biotechnological innovation have flexible boundaries. Intuitively, a number of possible actors can be identified in the innovation of enzymes X and Y reflecting the broad spectrum of activities and networks that entail biotechnological innovation and include individuals and organisations representing, *inter alia*, academic, commercial, consumer, financial and government interests. For example, the decision to follow the rDNA technology route for enzyme X is clearly influenced by the decisions and planning of the former director of firm A. Similarly, the CEC plays a significant role in regulating biotechnological innovation and setting up systems for its funding which feature in the innovation of enzymes X and Y. But the actors also cross-cut individual and/or organisational boundaries. For example, the CCGB highlighted in the innovation of enzyme Y, and which tackled the issue of communicating biotechnology to the public, can be viewed as being made up of a collection of actors. 'Actors' involved in biotechnological innovation are fluid and flexible concepts.

Eighth, biotechnological innovation is clearly more than a 'technological' process. In 'economic' terms, for instance, the increased competition of larger enzyme manufacturers, coupled with the decrease in profit margins in the sector more generally, led firm A to adopt and develop rDNA technology in the manufacture of GMEs. In 'political' terms, for both enzymes X and Y, the evolving interaction and tension between national and European institutions played a key role in the emerging regulatory environment around biotechnology. In more 'social' terms, the role of a key government advisor in the Netherlands in encouraging and promoting the cause of biotechnology was important in the setting up of systematic public funding initiatives for biotechnology which influenced the innovation of enzyme Y. And 'technologically', the decrease in time required for the innovation of enzyme Y compared with enzyme X suggests that some of the early problems with applying rDNA technology to the innovation of GMEs were overcome. The incentives for biotechnological innovation, therefore, are not purely 'economic', 'political', 'social' or 'technological' in nature. Rather, these different aspects are held together in particular ways in particular cases, but none are necessarily dominant.

Ninth, the various 'social' and 'technological' factors constituting biotechnological innovation highlight the existence of a multiplicity of independent networks, rather than one particular network. Whilst the previous point highlights the connections between 'social' and 'technological' aspects, the aspects of the network of biotechnological innovation display certain distinct and autonomous characteristics. To take a simple example, multilateral trade agreements have been shown to be connected to the innovation of enzymes X and Y. More especially, the TBT and SPS agreements ensure the transfer and export of GMEs between countries, but they rarely concern the day-to-day activities of the majority of research managers. Not one R&D manager mentioned developments in international trade regimes as a factor affecting innovation. Thus whilst the stories of the innovation of enzymes X and Y are presented as connected, indeed fused, to each other, they are part of the localised experience of innovation. In this respect, biotechnological innovation needs to be conceived of in terms of a multiplicity of networks.

Tenth, given the multiplicity of networks and actors and their seemingly fragmented and autonomous characteristics, the research points to the networks being

connected under particular geographical and historical circumstances. For example, in the Netherlands the importance of food safety issues and the need to regulate (agro-food) biotechnology took place at a time when there was a growing tendency to promote biotechnology amongst industrial interests. Similarly, in Denmark, the choice of *aspergillus* as a host for enzyme X rather than using *e coli* came at a time when *e coli* was seen to be the source of an outbreak of food poisoning associated with meat and dairy products in Denmark. This is not to say that the innovation of the GMEs and biotechnology is totally accidental, or that from seemingly illogical and paradoxical circumstances, logical constructs appear, but that the innovations emerge in unexpected ways according to how key actors, activities and conditions are linked.

Eleventh, biotechnological innovation is part of a capitalist industry driven by the need to accumulate capital. For firms involved in biotechnological innovation this point seems obvious: ultimately the innovation of enzymes X and Y is part of a strategy to make a profit for firms A, B, C and D. But for public institutions, the need to generate capital accumulation is no less important. In the case of enzyme X, for example, the considerable public expenditure on biotechnology is part of strategy to improve the international competitiveness of Danish industry and, therefore, increase its profits. Similarly, in the case of enzyme Y, the development and promotion of IPR by national and international interests is part of a generic strategy to protect industrial profits in the Netherlands. Of course, as highlighted by the regulation of biotechnology, motives can be socio-political. But in these instances, such as in the current debate about the labelling of GM foods in Europe, the interests of making a profit are generally included in discussions.

Although these eleven points provide a systematic account of key aspects of the network(s) that make up biotechnological innovation, the empirical evidence reveals that in broad terms the networks are fragmented, differentiated and stratified: they are fragmented because at times the networks appear broken and incomplete when considered in terms of the innovation of (agro-food) biotechnology; they are differentiated because the networks that have been outlined often can be distinguished from each other and are not necessarily connected to each other at the same time and place; and they are stratified because the networks of biotechnological innovation can be divided into different layers which take varying precedence over each other during

innovation. Returning to the models of innovation outlined in **Section 2.2,** although there are gaps in the picture above, it does cast doubt on the usefulness of some of the current attempts at conceptualising (technological) innovation. This study suggests that biotechnological innovation needs to be thought of as recursive, multi-dimensional and messy, and highlights the interdependencies and tensions between 'social' and 'technological' factors which cover a multi-stable, diverse and ambiguous set of actors, activities and conditions whose ends are probably not predictable. Both major and minor features of these actors, activities and conditions may arise for temporary local reasons but later become fixed and then predispose the context within which innovation takes place to a particular set of choices. Biotechnological innovation is not a random process; there are clearly ordered elements in biotechnology: it can be connected to some form of structure, regime or tendency; there are certain fixed patterns or states associated with it; there is some permanence and purpose to innovation; and it is built around certain rules, standards and procedures. But biotechnological innovation needs to be thought of in more specific and contingent terms. To borrow a notion from Law (1994), biotechnological innovation is better conceived as involving an 'ordering of contingency'. Fundamentally, though, the 'innovation milieu' is far broader and deeper than is currently recognised.

Clearly, this account of innovation of GMEs represents a particular configuration of actors, institutions and sites coming together in a particular ensemble. How typical this configuration will be for other biotechnological innovations is contestable - it is likely that the networks would have appeared differently if another biotechnological innovation had been examined. But it is reasonable to assert that the range of factors - the importance of regulation, the re-definition of public-private relations, and the critical mass around biotechnology, for instance - associated with the innovation of GMEs may have much in common with other aspects of biotechnological innovation. In addition, the overlapping and interaction of business, industrial, academic, government and consumer interests may be displayed in many other technoscientific developments. Indeed, the uncertainties, turbulence and controversy associated with biotechnological innovation have been found with other technologies such as in IT (Toffler, 1980) and the nuclear industry (Balogh, 1991). But based on existing empirical evidence, it is not possible to conclude with certainty whether

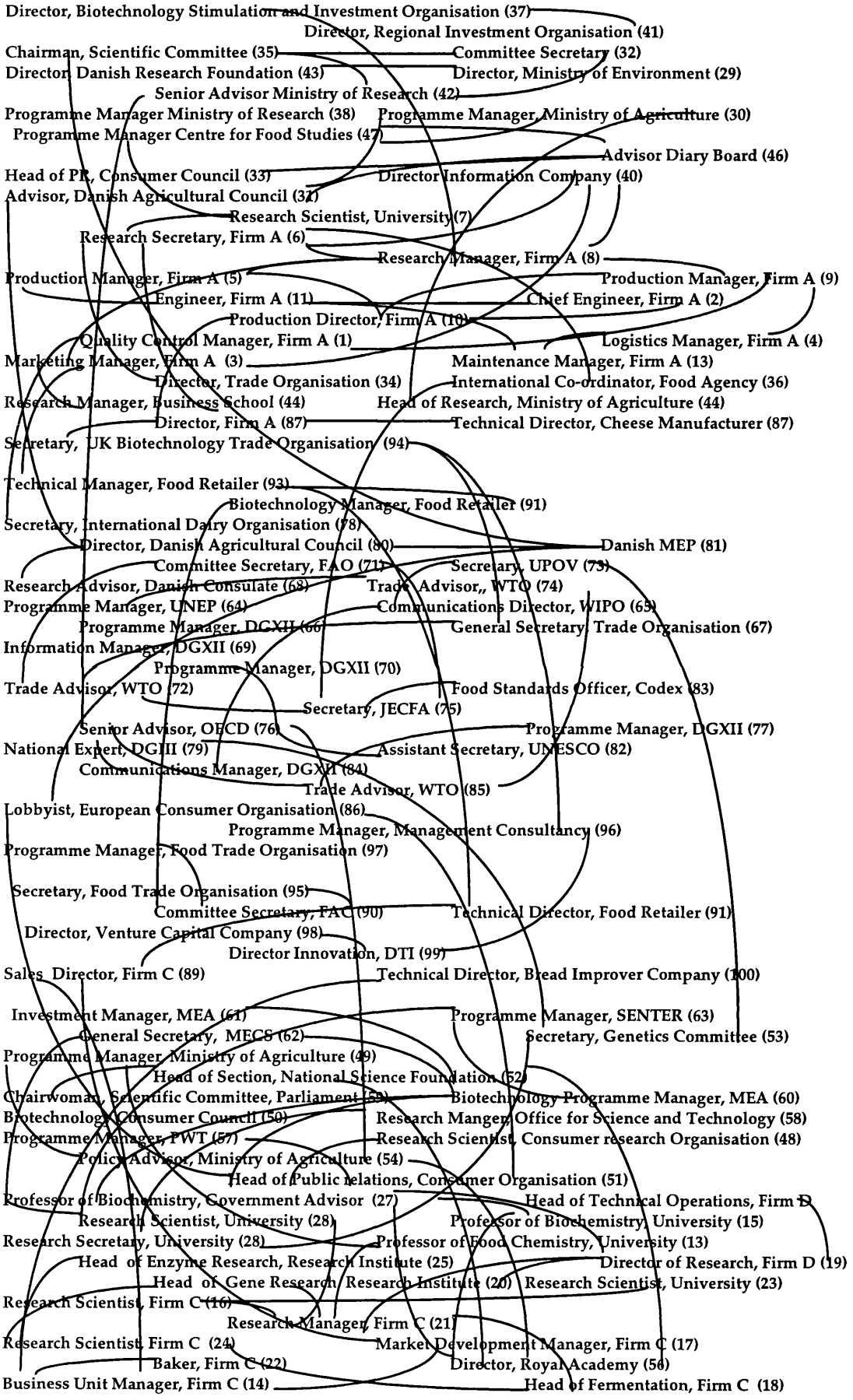
biotechnological innovation differs significantly from other sectors. Where, perhaps, the nature and characteristics of biotechnological innovation may appear different to other forms of technological innovation is from an epistemological-cum-ontological point of view as will be considered in the next two chapters. But overall the characteristics of innovation in (agro-food) biotechnology outlined in this chapter present a more complex and diversified view of innovation than suggested in other models.

6.5 Summary

In this chapter a description of how biotechnological innovation takes places is provided. The description is organised around seven stories of the network(s) of biotechnological innovation which emerges from the investigation. From the research, eleven general points about biotechnological innovation are made. Above all, this chapter shows that innovation in (agro-food) biotechnology is made up of a number of networks which display differentiated, fragmented and stratified features. This chapter proposes that biotechnological innovation is characterised by a multi-stable, diverse and ambiguous set of actors, activities and conditions whose ends are not altogether predictable. Fundamentally, the research points to a much wider and deeper 'innovation milieu'.

From the research a complex picture of biotechnological innovation emerges. Nevertheless, some broad characteristics can be identified, and the use of networks to conceive and examine biotechnological innovation raises important concerns and issues about both current conceptions of (technological) innovation and how best to model it. A significant issue emerging from the previous two empirical chapters centres on the role and nature of knowledge. This is especially important when thinking about whether biotechnological innovation is qualitatively different from other developments in technoscience because of the intimate connection to understandings of the gene and the manipulation of DNA. In **Chapter 7**, the next and final empirical chapter, examples and arguments presented in **Chapters 5** and **6** are reinforced and extended by exploring the networks of knowledge creation associated with biotechnological innovation.

Figure 6.1: The messy reality of biotechnological innovation



7

NETWORKS OF BIOTECHNOLOGICAL INNOVATION: KNOWLEDGE AND KNOWLEDGE PRODUCTION IN TECHNO-SCIENCE

7.1 Introduction

In this final empirical chapter, aspects of knowledge creation associated with biotechnological innovation are examined. **Chapter 5** shows a discrepancy between public perceptions and scientific appreciation of the actual and potential developments in agro-food biotechnology, and the possible connection of this discrepancy with the contested nature of the term 'biotechnology'. In **Chapter 6**, the networks of biotechnological innovation indicate that the process is multi-stable, diverse and ambiguous, and is influenced by particular geographical and historical conditions. These two empirical chapters correspond to the two main research questions around which this study in technoscience is organised. But behind both of these chapters lies a view about knowledge and how knowledge is produced in technoscience. Specifically, the manipulation and use of DNA in biotechnological innovation entails the creation, transfer and refinement of certain key understandings of the gene to specific applications. Indeed, one of the main reasons for the enormous interest in biotechnology is the perception that it is qualitatively different from other (new) technologies in the way knowledge is produced. Therefore, to understand further 'what' (agro-food) biotechnology is, and 'how' it comes about, it is useful to focus this analysis on the particularities of knowledge and knowledge production.

This chapter has five main sections. **Section 7.2** briefly outlines a view of knowledge connected to biotechnology. In **Section 7.3**, the multi-/inter-disciplinary nature of biotechnology and biotechnological innovation is examined. **Section 7.4** investigates the production of knowledge from a different angle concentrating on the connections between 'science' and 'technology' in the emergence of technoscience. In **Section 7.5**, the 'reflexivity' of knowledge production associated

with biotechnological innovation is explored. The main research findings in this chapter are discussed in **Section 7.6.**

7.2 Biotechnology as knowledge

Technology is part of a paradigm of knowledge which influences what it is, how it comes about, and how it is used (Russell, 1997). Whilst some authors question whether different conceptions of knowledge arise from different geographical or historical starting points (Martin, 1996:97; Webb, 1995), it seems reasonable to assert that different conceptions of knowledge may also emerge from different technological innovations. The notion that biotechnology is knowledge can be interpreted in a number of ways. One dominant way is to treat biotechnology as a means of manipulating and reprogramming the information codes of life found in living cells (Lash and Urry, 1994:99; Castells, 1996:30). Accordingly, biotechnology is viewed like IT as it comprises an information management activity (Schiller, 1997:114). As Yoxen (1988:198, in ibid.; emphasis in the original quote) on the more general issue of biology writes:

> 'it treats organisms as information-processing machines. They begin as packets of information; they organise themselves through a process of programmed self-assembly; they operate on the environment in a controlled manner according to genetic instructions; they reproduce by condensing their structures and functional coherence into a transmittable form - that carries a message containing the instructions in a code that organisms can "read." To think of life in this vocabulary is basic modern biology.'

Genes, then, are like micro-chips and can be used to store information.[1] And therefore, genetic information through biotechnology can be employed in a range of economic activities - from the production of food to the development of drugs for human health care - which have some biological base. But information is not knowledge. Understanding the nature of knowledge is a major concern in social science (Webb, 1995). Knowledge varies over time and space and, therefore, is associated with a degree of uncertainty. According to Fransman and Tanaka (1995:433), whilst information is 'closed', knowledge is 'open', as the latter continually evolves and

[1] Interestingly, Bill Gates recently remarked that 'this is the information age, and biological information is probably the most interesting information we are deciphering and trying to change' (*Guardian*, 1998e).

develops. In this respect, knowledge has a cumulative effect (Russell, 1997) and, unsurprisingly, it is genetic knowledge - its creation and use - rather than genetic information, which is viewed as the crucial dynamic in the economy (Fransman et al., 1995). Of course, there are many aspects of genetic information useful to socio-economic development and change (Price, 1995; Grace, 1997); for instance, the ability to identify particular genetic characteristics in the human genome may radically change human health care (Hamilton, 1998). But it is genetic knowledge, such as breakthroughs in the early technological foundations of biotechnology through gene splicing and rDNA technology, that will be more significant for socio-economic development (Fransman et al., 1995; Castells, 1996:48). In a general sense, (bio)technology can be viewed not only as a product of knowledge but as knowledge itself (Strange, 1988; Russell, 1997).[2]

But genetic knowledge, and its application in biotechnology, is perhaps different to IT and other technologies in the way it encourages notions about power over life and death (Kareiva and Stark, 1994; Terranova, 1996; Hamilton, 1998; see also **Section 1.1**). Much has already been written about the momentous moral and technological issues raised by advances in biotechnology not least of its ability to interfere with 'nature' and 'creation' (Jones, 1996; Levidow, 1996; Straughan, 1996; Squier, 1998). Despite technological issues which point to difficulties with creating new life forms (see **Section 5.2.6**), there remains considerable unease about exploring the 'secrets of life' (Keller, 1992; Macer, 1996). The centre of biotechnological activity is in a particular component of a cell, namely in the genetic material or in the gene (Keller, 1992:96). Through Crick and Watson's discovery of the double helix structure of DNA (see **Section 3.2**), biotechnology is associated increasingly with a certain scientific hegemony (ibid.:107; Haraway, 1992) and a general ascendancy of the life sciences (Bronowski, 1977; Levidow 1996). For example, the HGP, which aims to locate and define every gene in the set of human chromosomes, is proposed as a means of scanning DNA abnormalities, from which a genetic cure can be devised for many diseases (Hamilton, 1998:42). Quite apart from the fact that many diseases are not genetic (ibid.), the power of genetic knowledge is such that it can be used in

[2] Strange's (1988) influential view on 'knowledge' is based around the idea of a 'knowledge structure'. Whilst I agree in principle that knowledge is a structuring force in modern capitalist societies, I feel less comfortable with the view that it has totally replaced 'capital' as the dynamic for change and development. As I argue subsequently, knowledge is a form of capital. Importantly, whilst capital has not been explicitly examined, the importance of capital accumulation for technoscience is an underlying theme in this thesis (see **Chapter 8**).

legitimate particular social ideologies, such as racism, eugenics, stigmatisation and genetic reductionism (Leng et al., 1995; Kerr et al., 1998). Biotechnology as knowledge, therefore, encourages particular socio-economic relations.

This representation of biotechnology as knowledge remains incomplete without emphasising the role of capital. Capital, through the development and application of biotechnology, has become more exercised in the management of organisms and the manipulation of genes (Dicken, 1996:112; Buttel, 1998). As highlighted in **Section 2.4.1**, in the agro-food system, through the processes of *appropriationism* and *substitutionism*, agriculture is increasingly being taken over by industry (Goodman et al., 1987). And with the emergence and development of rDNA technology, the entire process of biological transformation is increasingly falling under industrial control (Goodman and Redclift, 1991:10; Goodman and Watts, 1994).[3] It is this process that prompts some writers to suggest that the creation of (biological) knowledge is the driving force in modern capitalist societies (Strange, 1988:115; Fransman et al., 1995; Kenney, 1997:89-90).

Knowledge associated with biotechnology is not only manipulated by capital; it can also be viewed as a form of capital as it is increasingly treated like a commodity. This trend goes back to the introduction of systems of patents and copyrights (Tiles and Oberdiek, 1995:108). Indeed, IPR is often viewed as driven by the fact that it is knowledge that creates value in modern capitalist societies (Kenney, 1997:96). The patenting of knowledge associated with biotechnology, however, is not restricted to seeds and agricultural inputs (Kloppenburg, 1988). Since the 1980 Diamond vs. Chakrabarty case in the US, which allowed living material to be patentable (Kevles, 1994; Grace, 1997), and the ensuing story of Du Pont, Harvard, and OncoMouse™ (Haraway, 1997), 'life' itself is now commodifiable (see **Section 6.3.6**). Taking these points together, it can be suggested that the understanding and manipulation of the knowledge of the gene is part of a wider strategy of capital. Biotechnology, therefore, is not merely an endogenous influence on innovation but a fundamental aspect of 'knowledge' driving modern capitalist societies.

[3] Such developments are leading to the emergence of a bio-industrial complex which is transforming traditional agro-food systems and is dominated by industrial capital (Byé and Fonte, 1994; Goodman and Watts, 1994; Ahson, 1996a).

7.3 Biotechnology: a coming together of knowledge

Most definitions of biotechnology evoke a particular view of knowledge. Take for example the OECD's (1992:29) definition of biotechnology used earlier in this thesis, 'the application of biological organisms, systems, and processes based on scientific and engineering principles, to the production of goods and services.' Or take the definition of biotechnology from the EFB (1995), 'the integration of natural sciences and engineering sciences in order to achieve the application of organisms, cells, parts thereof and molecular analogues for products and services'. As both these definitions suggest, biotechnology is not a separate or distinct science or technology but rather involves a range of disciplines or areas of knowledge (see **Section 3.1**). More specifically, it encompasses the use of skills and knowledge drawn from, *inter alia*, biology, biochemistry, genetics, microbiology, biochemical engineering and separations processing (Europabio, 1997:21). Biotechnology, therefore, can be said to exhibit both multi-disciplinary and inter-disciplinary characteristics: it is multi-disciplinary in that it is seen to involve the working together of different disciplines or areas of knowledge; it is inter-disciplinary because it entails the notion of a new integrated approach to the understanding and manipulation of genetic material.[4]

If biotechnology is intrinsically multi-/inter-disciplinary, biotechnological innovation needs to combine different areas of knowledge and disciplines as well as interact with others. This argument is not without foundation as there is some evidence to suggest that such multi-/inter-disciplinary developments occur in biotechnological innovation. For example, systems that combine biological and chemical molecules, on the one hand, and physical devices and electrodes, on the other, have a huge potential in many applications (Thomas, 1995), such as in nanotechnology (the making of ultra small components and devices) to create materials with electronic and optical properties (Pendick, 1997). Similarly, with our increasing knowledge of the human genome the functional control of health and disease which will require the convergence of medicine and computing will mark out a new area of technoscientific enquiry (Poste, 1998).

[4] See also **footnote 3, Chapter 3**.

Despite the uncertainty with the term 'biotechnology' as shown in **Chapter 5**,[5] the research also points to the multi-/inter-disciplinary nature of 'biotechnological knowledge'. To start with, there is evidence in support of the notion that biotechnological knowledge involves the interaction of many areas of knowledge:

> "I think it is a combination of microbiology, bio-processing and up-scaling and downstream processing, so it is a mixture of various disciplines...and molecular biology of course....If you talk about biotechnology almost everybody knows what you are talking about. But if you ask me what is its definition you come with a lot of disciplines....When you say biotechnology the first thing I think of is production, making use of micro-organisms, plants to produce something beneficial." HS, Head of Fermentation and Downstream Processing, Firm C, The Netherlands

Two important aspects of biotechnological knowledge emerge from this interview extract. Firstly, some areas of knowledge, such as microbiology and bio-processing, appear especially prevalent in many descriptions of biotechnology. Secondly, it is less clear whether biotechnological knowledge is multi-disciplinary and/or inter-disciplinary; that is, does it represent a new and distinct paradigm of knowledge or is it merely a collection of knowledges loosely held together? This lack of clarity is a strong theme throughout much of the research and points to a degree of ambiguity over what biotechnology as knowledge entails.

Further clues to the nature and characteristics of knowledge associated with biotechnology are found in discussions about what connects it together. One person working at the CEC is of the following opinion:

> "Biotechnology is dealing with all kinds of biological matter, living matter on a cellular and molecular level, biological knowledge.....It will be integrated in other fields...that is logical because it is in fact a bundle of knowledge and technologies which are quite different but have a common point, living matter, but that is too big and too different." BZ, Information Manager, Biotechnology, DGXII, CEC, Belgium

Leaving aside the nature and scope of the integration of biotechnology, according to this interviewee, 'biotechnological knowledge' is connected together through an understanding and use of knowledge about cells. This focus on the cell, which draws on knowledge about the gene, corresponds to more general claims about biotechnological knowledge (see **Section 7.2**). The interviewee also emphasises the notion that

[5] Some elements of the discussion in this chapter echo issues highlighted in **Chapter 5**.

biotechnology is a loose collection of knowledges with a common point. It is easy to underestimate the significance of the discovery of the structure of DNA in connecting various areas of knowledge (see **Section 3.2**). But it is also reasonable to assert that there have been more incremental developments in biotechnological knowledge which may only be partially connected to the study of DNA, such as understanding the conditions under which enzymes can work (see **Section 6.2**), but which are also pivotal for identifying the nature of knowledge.

Despite this belief that biotechnological knowledge is a fairly loose construct, it still does not detract from the significance - not least in socio-economic terms - of connecting these different areas of knowledge:

> "...you have had just one great big surge in understanding, and then a long process of ingestion in which the digestion is quick and easy in leading-edge science based areas like immunology and vaccine development, but it is going to take a lot longer to be accepted routinely in the food processing industry....There is a sense of inevitable diffusion...it is totally obvious that slowly in some areas and rapidly in others, it would change everything in the sense that the knowledge is absolutely pervasive, its diffusion is absolutely inevitable, you can't put times and dates on it but there is no going back."
> MC, Senior Advisor, Biotechnology, OECD, France

This interviewee makes two important points. The first is the overall significance of the knowledge associated with biotechnology. This thesis is premised on the belief that biotechnology is potentially of enormous strategic importance for modern capitalist societies (see **Section 1.1**), a view echoed above. By extension, as described in **Section 7.2**, biotechnological knowledge is associated with significant changes in socio-economic activity. Secondly, despite the importance of being able to manipulate the gene, its acceptance and diffusion through different socio-economic activities depends on a range of conditions and factors. Some of these conditions and factors have been identified in **Chapter 6**, but it is important to recognise that the creation and transfer of biotechnological knowledge does not take place in a vacuum. Interestingly, as far as the nature of biotechnological knowledge is concerned, the interviewee goes on to make another crucial point:

> "For biotechnology, I have repeatedly used the old Hindu story of the 5 blind men and the elephant. That none of them is a competent elephant handler, one has got the ear, one has the leg, one has got the side, one has got the tail and so on, but none of them see the whole thing. So you see the need for a holistic perspective, or perhaps you don't need a holistic perspective...perhaps it just continues to be managed in pieces, but if you want to present it coherently for the purposes of exposition then you need

more than just the perspective of the Ministry of Agriculture or the Ministry of Research." MC, Senior Advisor, Biotechnology, OECD, France

Thus again biotechnological knowledge appears not to be uniform and coherent but loosely defined. Not surprisingly, it is not possible for people involved in biotechnological innovation to have an accurate sense of all developments and applications - actual and potential - taking place in this area. This feature of biotechnology exists even though the focus on the gene can be thought of as being a powerful connecting point.

The boundaries of biotechnological knowledge, therefore, appear fluid and flexible. This seemingly ambiguous nature of biotechnological knowledge is complicated by evidence that suggests it interacts, but not necessarily combines, with other areas of knowledge:

"...when you look at the biosciences (biotechnology), and if you see that in order to get the results of all that scientific work, in the form of products and processes that need to be applied, then you need lots of other disciplines. And biotechnology is also a term which brings lots of other disciplines together, it can be computer technology, it can be down stream processing, it can be chemical technologies; all those kinds of things can be of importance in a certain stage in the development. And biotechnology is by definition, a really multi-disciplinary activity, from the basic sciences to the very much applied technologies which are necessary to pack the products in its latest versions and get it to the shelf on the supermarket." RM, Director, Biotechnology Industry Trade Association, The Netherlands

In this instance, some broad view on what biotechnological knowledge covers is advanced whilst at the same time recognising that it is distinct from other areas. But equally, there is a lack of any clear distinction between its multi-disciplinary and inter-disciplinary features.

Many questions remain about the coherence and distinctiveness of biotechnological knowledge. But one issue seems absolutely clear from the interview extracts above: it is difficult to separate discussions about 'what is biotechnology?' from the debate about 'what is biotechnological innovation?', as many interviewees confuse discussions about the nature of biotechnological knowledge with those on the means by which biotechnological knowledge is produced. As noted in **Section 3.1**, biotechnological innovation requires different areas of knowledge and disciplines to come together. Indeed, echoing comments about the multi-/inter-disciplinary nature of

biotechnology, biotechnological innovation can be distinguished by an attempt to combine different knowledges. As one research scientist succinctly puts it:

> "I think that biotechnology is a multi-disciplinary field as you do find inputs from many different researchers and different fields making it more diffuse and flexible and different." JN, Research Scientist and Director of Biotechnology Trade Organisation, University, Denmark

The interaction between different disciplines is shown further by the importance of other technologies for biotechnological innovation. From the postal questionnaire (see **Appendix A**), for example, the importance of certain technologies for developments in modern agro-food biotechnology is clearly seen (see **Table, 7.1**).

Table 7.1: Importance of other technologies for agro-food biotechnology

Likert scale: **Least important** ⇒ **Most important**

Telecommunications	3	22	31	28	16
Computers (Hardware)		26	39	19	16
Computers (Software)		13	32	29	26
Computer Aided Design	10	27	23	27	13
Computer Aided Manufacturing	15	25	30	15	15
Robotics	7	31	38	14	10
New materials	7	14	24	21	34
Microchips	3	19	32	16	30

Total number of respondents (n) = 45; figures in percentages

Despite problems with the scope and presentation of these data,[6] several other technologies are viewed as important for the development and application of (agro-food) biotechnology. The production of knowledge around biotechnological innovation involves a range of technologies, some may be considered as integral to what constitutes biotechnology, and others are more usefully thought of as feeding in and influencing the innovation. This view is supported in the interviews:

[6] Three qualifications on these data are important here (see **Section 4.3**). The first is that only a narrow set of technologies are investigated in the questionnaire; other areas such as nanotechnology which are increasingly seen as important for biotechnology are neglected and perhaps reflect the age of the questionnaire. Second, it is hard to make any unequivocal statement about the importance of these technologies in comparison with each other because of the small sample size and the even distribution of results. Third whilst the total number of respondents is 45, they were able to tick more than one box.

"we try to get people from the technology department to work with us at a very early stage....If you look at the biotechnology we are doing, one of the areas people are very active in is computer supported modelling and analysis....These technologies are vital for us." BS, Head of Biotechnology, Multinational Chemical Company, The Netherlands (my translation)

But whilst possible multi-disciplinary and inter-disciplinary features of biotechnological innovation come out of this interview extract, overall, there is a lack of a consensus on this distinction.

Notwithstanding the lack of a clear idea about whether biotechnological innovation entails multi-/inter-disciplinary features, the need to encourage such an approach is recognised as important. As one interviewee responsible for promoting biotechnological innovation in the UK says:

"we are trying to bring people together...because we believe biotechnology has huge potential but it is facing a number of hurdles....We have to encourage more synergies in biosciences (biotechnology) across industrial sectors especially amongst the different technologies." PM, Director, Innovation Unit, DTI, UK

But there is a danger in thinking that the need to encourage multi-/inter-disciplinary approaches in biotechnological innovation identified in the previous interview has actually be translated into reality. This reflects further on a dominant theme in this thesis, the discrepancy between actual and potential developments in agro-food biotechnology (see **Chapter 5**). There are many problems with undertaking multi-/inter-disciplinary research. In an interview extract worth quoting at length, one research scientist highlights some of these problems:

"It is easy to talk to them (chemists), but it is not easy to understand each other [Why not?] I think we use another language. Chemists talk about molecules when they interact with each other. And biochemists talk in terms of much larger structures which are not well defined....And often I have the problem that when we make some compound here and then send it over to biochemists to test, they want it quickly and so we make them quickly and not very pure...and then they get no results and then they say 'what have you done and why don't it work?' They don't know anything they just try some...prescriptions in the literature and if it doesn't work they then throw it away. They are not interested in explaining 'why'. It's totally another dimension...And chemists, or most chemists, don't do an experiment until they know what they put into it and they know the conditions and...if it doesn't go right they ask 'why' and they test the systems and they try to find out what happens instead....I think also biochemists think...that when I deliver a compound to them they assume it's quite pure, 99.9 percent, they don't think about impurities [Does that make a big difference?] It can make the whole difference, because there can be some small impurities which destroy the enzyme system. There are so many things that they don't think about. That is one thing, and there is another thing is that when they talk about their systems they don't talk in molecules...they talk in much

> higher structures [For instance?] I mean they talk about cells, which is...that could be a virus infection or something in the cell, and they want to stop that. And then they talk about...which...systems are going wrong in the cell. They don't talk about a molecule which goes to that. You have to force them to do that...they don't talk in molecular biology." OD, Research Scientist, University, Denmark

Several interesting points need to be expanded upon from this interview extract. Firstly, there is a difference in the units of analysis used by different people involved in biotechnology which impacts upon how problems in innovation are constructed and addressed. Although simplified considerably, the interviewee makes the point that the different focus on cells and molecules has distinct effects on biotechnological innovation. The way certain units or elements of biotechnology are viewed differently is also expressed by another interviewee:

> "Well, for example, biochemists and chemists look at a catalyst in a very different way....I always see my organic chemistry colleagues just treating enzymes like an ordinary catalyst. And, well, it is an ordinary catalyst but you have to know something about its sensitivity and how to handle it....An organic chemist would say 'it's just a catalyst' and in fact it's not." BS, Head of Biotechnology, Multinational Chemical Company, The Netherlands (my translation)

Secondly, and echoing a point made about biotechnological knowledge, there is a lack of an overall understanding and appreciation of the scope of knowledge in biotechnology amongst many people undertaking biotechnological innovation. As the example of impurities in particular chemical formulae in the initial interview extract highlights, what for some people may only be considered a minor impurity (0.1 percent) and therefore easily ignored, for others this level of impurity may make an enormous difference during R&D. This point highlights some divergence between areas of knowledge considered important for biotechnological innovation. This notion is supported by further evidence on the lack of experience amongst people involved in multi-disciplinary and inter-disciplinary work:

> "....it is a big problem because people are trained in their own discipline. Disciplines are more or less tools with their own sources. Quite often you get a problem in communication between these disciplines....And you have another problem, you have the problem that some disciplines have difficulties in communication but you also have an enormous problem getting scientists or people working in fundamental, basic science to get them to communicate with technologists." RS, Professor of Biochemistry and Senior Government Advisor, The Netherlands

A third issue is the difference in 'language' people use in biotechnological innovation. Whilst intimately connected to the way problems are conceptualised and

addressed in different disciplines, and the consequent hierarchy this encourages in terms of the importance of certain issues over others, there is strong evidence from the research that getting people to work across disciplines is problematic. Talking about biotechnological innovation, another interviewee comments:

> "It is extremely difficult because of the difference in language. A micro-biologist thinks and speaks in another language than a process technologist. And that is an important gap which you have to bridge especially in research organisations where you are all focusing on the same objective. As a manager you definitely have the task to make sure that these people have their nose directed in the same direction." WM, Project Manager for Biotechnology, SENTER, Executive Agency of the MEA, The Netherlands

This view is not unusual and reflects the general difficulties in undertaking any form of multi/inter-disciplinary work. But what does need to be highlighted is that biotechnological innovation requires, indeed places a premium on, multi-/inter-disciplinary approaches. Thus from this account, problems with 'language' present a considerable hurdle for successful innovation in biotechnology.

A fourth and final point is that the differences in language seems to reflect a broader development in technoscience which hinders biotechnological innovation. As one person describes:

> "With increased specialisation it is difficult to 'talk' to people from other areas. That is you might have some broad things in common but still do things differently. In fact it is possible to say that what you have in common is becoming less and less and therefore the gap between disciplines is getting wider." ME, Research Director, Firm D, The Netherlands (my translation)

The nature of technoscience is such that increased specialisation is increasingly becoming prevalent, and this feature, highlighted in biotechnological innovation, acts as a barrier in undertaking multi-/inter-disciplinary work. The broader significance of this in terms of developments in technoscience notwithstanding, for the present discussion it is useful to assert that in the production of knowledge there are a range of barriers which prevent them from interacting easily.

Problems with encouraging greater co-operation between disciplines and areas of knowledge are well documented in the history of biotechnology. But these problems have not been confined to the laboratory. For example, the CEC set up the Concertation Unit for Biotechnology (CUBE) to monitor and promote developments

in biotechnology by bringing in different interests and disciplines.[7] Certain knowledge, information and views about biotechnology, especially in terms of its role in improving European industry, began to emerge in the 1980s which suggested the need to encourage multi-/inter-disciplinary and cross-institutional arrangements, a task CUBE set out to achieve. But as the former head of CUBE points out, this attempt was short lived:

> "CUBE was effectively murdered. It was responding to all the people across the Commission who had partial interests...but it was unsuccessful in the end because we were in DGXII and there was a great deal of inter DG suspicion" MC, Senior Advisor, Biotechnology, OECD, France

CUBE was 'murdered' because many other institutional arrangements - DGVI for instance - felt that DGXII was monopolising the 'revolutionary' potential, and attached political kudos, associated with biotechnology. The production of knowledge associated with biotechnological innovation evidently has a 'political' dimension. Ironically, in the name of multi-/inter-disciplinarity, the ending of CUBE presented an opportunity for the CEC to devise another strategy for promoting biotechnology:

> "Well there is going to be a life science programme, life sciences and technologies programme, and biotechnology will be well absorbed within that....I think it is a very sensible way to go. It is the whole of the life sciences that are going to benefit and many people speak of the 20th century, the 21st century as the biological age." ML, Programme Manager, Biotechnology, DGXII, CEC, Belgium

Despite different attempts to encourage multi-/inter-disciplinary approaches throughout the innovation environment, problems remain with the creation of knowledge in biotechnological innovation. This problem may be connected to the fact that whilst multi-/inter-disciplinary work is seen as desirable, as with 'biotechnology' (see **Section 5.3**), there is a 'fashionable' dimension to it:

> "You may well ask whether biotechnology is genuinely multi-disciplinary, because we have seen a tendency of research groups going together when they apply...and they just use their money for their own purposes without a substantial synergy effect." PG, Senior Advisor, Ministry of Research, Denmark

[7] For a history of CUBE and other regulatory developments associated with biotechnology, see Cantley (1995).

In this sense, the touting of the multi-disciplinary nature of biotechnology is used to raise funds because the creation of synergies is seen to be a desirable and necessary feature of successful innovation in modern economies.

In sum, from the discussion above, two important views about biotechnological knowledge and the way it is produced emerge. The first is that although biotechnological knowledge is said to entail both multi-disciplinary and inter-disciplinary features, this notion does not readily match the reality of the evidence. Generally, it seems more appropriate to suggest that there is a great deal of ambiguity over the precise nature of biotechnological knowledge, particularly in terms of the nature and characteristics of the knowledge it is said to entail. This is not surprising and supports the uncertainty with the term 'biotechnology' outlined in **Section 5.3**) Importantly, this ambiguity is mirrored in the way biotechnological knowledge is produced. Secondly, the uncertainties with knowledge and knowledge production highlight a dynamic in the interaction between these two dimensions. That is, the deep insecurities about the multi-/inter-disciplinary nature of biotechnology influence, and are influenced by, attempts at successfully undertaking biotechnological innovation. Evidence of this dynamic is also seen in broader relations between science and technology.

7.4 From technoscience to techno-science

The characterisation of knowledge and knowledge production in biotechnological innovation can also be examined from the standpoint of the emergence of technoscience. The emergence of technoscience as a defining feature and function of modern capitalist societies is outlined in **Section 2.3**. As the term implies, one of the major features of technoscience is the increased links between science and technology (Latour, 1987, 1996; Menser and Aronowitz, 1996; Davis et al., 1997; Haraway, 1997). Biotechnology is said to exemplify this development as new opportunities are being opened up at the 'science-technology interface' (Laidler, 1997; Strohman, 1997a,

1997b). Distinguishing between science and technology is increasingly difficult (see **Section 2.2**). One common point of view from the research is:[8]

> "A difference between science and technology...I think there is not much of a difference. In my opinion the difference is in the approach...when you say science I think about pure science and I think about people developing their approach to produce new knowledge. With technology you have the same thing but you also have an eye for applications....[Is it a useful distinction?] I don't think so." AV, Professor of Food Chemistry, University, The Netherlands

This interviewee finds it unhelpful to distinguish between science and technology, and it can be argued from the interview extract that biotechnology is an extreme example of technoscience.[9] This view is supported by further evidence:

> "Here I am a little bit heretic! I don't, I really don't believe in the distinction between 'science' and 'technology'....I guess my point of view is influenced by my involvement in biotechnology....it is not easy to come up with a precise definition of biotechnology....And this is one area where it is difficult to say this is 'science' and this is 'technology'." PL, Director, National Research Foundation, Denmark[10]

---

[8] For my part, writing science and technology instead of technology and science is purely for stylistic reasons and does not indicate any 'ontological' preference.

[9] The ascendancy of biotechnology and the life sciences is mentioned in several other places in this thesis (see **Sections 3.2** and **7.2**). But during the investigation of the relationship between 'science' and 'technology' a number of additional points emerged. For instance, according to a senior government advisor on biotechnology to the Dutch government, biotechnology is replacing some of the older chemical techniques and, as a result, developments and research in these areas are slowing down. By contrast, the Vice President of a pharmaceutical multinational in Denmark suggests that rather than seeing the ascendancy of the biological sciences, we are finding the chemical industry using the biological processes. From the research, no overall consensus on this issue exists.

[10] It is also interesting to think about how 'science' and 'technology' are conceived and constructed in different cultural contexts. Little research appears to have been done on this subject, but Kealey (1996) in a connected vein argues that there are distinct national cultures in R&D. He proposes that the laissez faire economic attitude in Anglo-phone countries has spilled over into science and technology policy. What is more, he argues that this has put them in a stronger position when it comes to converting science and technology into products and processes for the market compared with the more *dirigiste* countries of Continental Europe. Speculatively, one explanation for differences between the way science and technology have been institutionalised is linked, according to the Director of the Danish National Research Foundation, to the differences in the development of the industrial revolutions in developed countries. He felt that in the UK it was initiated and run by industrialists; in Denmark, on the other hand, the industrial revolution came 100-150 years later and was managed by 'university educated people'. This difference he says contributed to a greater emphasis on government policy on science and technology policy in Denmark. Whilst this suggestion is difficult to substantiate and is certainly beyond the scope of this thesis, it is reasonable to advance the notion that cultural and historical contexts do impact upon technoscience.

Biotechnology appears to entail a total fusion between 'science' and 'technology', with them relating both to the practices of technoscience and the knowledge associated with it. In broad terms, then, biotechnological innovation requires the coming together of 'scientific' and 'technological' knowledges.[11]

And yet despite the attractiveness and range of arguments made about the notion of a fusion of science and technology making up technoscience, there is no overall consensus on the issue from the research. Another common view maintains a strong distinction between 'science' and 'technology'. Frequently, this is framed in terms of 'application' or 'purpose':

> "A difference between science and technology, yes there is, to me science is...about developing understanding. Technology is developing the uses of that understanding within a specific environment....the science is the basic research, either the research into new functional ingredients or the research into developing greater understanding of the basic foodstuffs you need to manipulate the basic raw material, and the technology is applied." DW, Business Unit Manager, Firm C, The Netherlands

This distinction between 'science' and 'technology' features strongly in the literature (see **Section 2.3**). Crudely put, 'science' focuses on understanding what takes place in biotechnology. For instance, in the innovation of the GM chymosin (enzyme X) described in **Chapter 6**, 'scientists' are more inclined to investigate the animal rennet gene, how and why it works, and how it might be inserted into a growth organism such as *aspergillus*. In an equally crude sense, 'technological' knowledge is more likely to focus on the application and production of biotechnology. Therefore, in the case of enzyme X, 'technologists' focus more on how to produce large quantities of GMEs for use in the manufacture of cheese. According to this point of view, 'scientific' and 'technological' knowledge represent different aspects of knowledge production in biotechnological innovation.

---

[11] At the same time the problem of distinguishing between science and technology can be related to the highly contested and varied use of biotechnology (see **Section 5.3**). That is, science and technology are themselves slippery terms and may be used, like biotechnology, in different ways. This becomes especially apparent when some interviewees began to talk about 'applied' and 'pure' science in the same breath as science and technology. For my part, from the research the only difference I have been able to detect between 'applied' science and technology is that the latter also is used to refer to the hardware, such as computers and machinery. But as argued earlier in this thesis, this is too narrow a view of technology and needs to be extended further (see **Section 2.3**).

In keeping with the above distinction, many interviewees separate 'scientific' and 'technological' activities when talking about biotechnological innovation:

> "Well there is of course, basic genetic work, that is what you would call 'science' or pure science if you like. I'm not sure whether we do any of that here....I guess everything we do here is technology because ultimately it has the purpose of creating new processes and new products for us....I also guess that the fundamental steps that led to the advent of gene technology, they were science, because it can't have been possible, from the very beginning for people to see where it was leading. Of course at a certain stage, perhaps in the early 70s...perhaps the fog began to lift and it became apparent to those who really knew about it that something was coming up." JS, Research Secretary, Firm A, Denmark

Paradoxically, the knowledge around gene 'technology' is treated as more 'scientific' - the discovery of the structure of DNA and the recombinant technology for their transfer are considered to contribute to the basic understanding of (modern) biotechnology. The 'technological' aspect of biotechnological innovation mainly centres on how some of this knowledge can be applied to particular (socio-economic) problems. In the example of the development of enzyme X (see **Section 6.3.2**), the cloning of the chymosin gene into a host organism (*aspergillus*) can be conceived of as the 'scientific' part of the innovation; the actual scaling-up of the fermentation of the host during production may be thought of as more 'technological' (see **Section 6.3.6**). Interestingly, the reference to the (19)70s confirms that the discovery of rDNA technology by Boyer and Stanley is as an important development for biotechnology as the discovery of the double helix structure of DNA (see **Section 3.2**).

The distinction between 'scientific' and 'technological' knowledges and activities raises some interesting questions. One issue is the extent to which 'scientific' and 'technological' knowledges are linked or fused together. Some evidence on this issue can be found by looking at certain institutional arrangements. In the Netherlands, for example:

> "The reason that we always speak in the Netherlands about Science and Technology is because the contact with industry on their technological development is mainly maintained by the Minister of Economic Affairs and his people. And the contact with the public funded science field is mainly maintained by the Minister here....Because that has been split we always speak about science and technology." RW, Director-General of Science, MECS, The Netherlands

The dichotomy between the funding of science and technology on an institutional level is perhaps too stark; in fact, it is important to point out that in the Netherlands there are

institutional arrangements that link these two activities together, such as Senter, an executive agency of the MEA. Nevertheless, the dichotomy does highlight how the distinction between 'science' and 'technology' remains strong amongst, for instance, 'political' interests. Added to this, institutional divisions are frequently carried over into the 'spaces' where technoscience is undertaken; for example, in Denmark, technical universities (such as the Danish Technical University [DTU]) which aim to develop more 'applied' methods are an important institutional element in the innovation environment in biotechnology.[12] But as the previous interviewee notes, the split into science and technology is not necessarily desirable nor useful for the innovation environment,[13] and there is a strong sense throughout the research that the knowledges and activities associated with 'science' and 'technology' need to be integrated more fully. Notwithstanding this reluctance to endorse the division between science and technology in institutional terms, under the circumstances described above it is not surprising that people involved in biotechnological innovation maintain some form of distinction between the two.

The production of knowledge around biotechnology has clear institutional and organisational features. Therefore, the framing of the distinction between science and technology within the context of broader socio-economic aspects is paramount. An interesting dimension to how knowledge in biotechnology is conceived is related to broader links with society:

> "I guess science is more driven by curiosity and technology should also be driven by what industry wants and by what society and what consumers can do with it...." RV, Research Secretary, University, The Netherlands

---

[12] In general terms, the emergence and growth of technical universities in mainland Europe is seen to reflect a desire to undertake research that can be more easily applied to the needs of society. But whether there is a qualitative difference in the types of research that are undertaken in these types of institutions compared to more traditional universities is hard to ascertain accurately from the research and is beyond the scope of this study. Superficially, though, many of these more 'applied' institutions claim or promote themselves as being more focused on the needs of society. And given the current focus of EU funded R&D this is likely to remain (CEC, 1996b, 1998b).

[13] Frequently, these institutional divisions have a long history. A case in point is the setting up of a rival 'academy' (Forum for Technology) to the *Koninklijke Nederlandse Akademie van Wetenschappen* (Royal Netherlands Academy of Arts and Sciences) by key figures (such as the vice president of Fokker) involved in industrial R&D to lobby for, and encourage, R&D activities which would better suit the interests of industry.

Generally, science and technology not only appear connected to different aims but also different concerns (see **Section 2.3**). Two specific points are important. Firstly, there is a suggestion that 'technology' is driven more by the needs of industry and, therefore, may encourage a different strategy towards capital accumulation compared with developments in science (see **Section 2.4.1**).[14] Second, the belief that technology is more commercially orientated hints at a closer link to the public domain. Technological innovation is undertaken with potential market possibilities in sight. Although simplified considerably, there is a feeling that the motives and practices of science appear more distant from consumers; technological aspects, on the other hand, seem more relevant and easily integrated into the broader socio-economic needs of society. Of course, it is easy to forget that individuals involved in science and technology are themselves consumers and, therefore, there is inevitably an input on the part of consumers and society in all aspects of technoscientific innovation. But there is some sense emerging from the research that science and technology can be distinguished according to what they produce (understanding or things) and who they are produced for (the scientific/academic community or wider interests in society). For the production of knowledge, this distinction in goals provides further evidence in support of the notion that the 'science' and 'technology' in biotechnology may be viewed as different and distinct.[15]

---

[14] This is not to say that technology is necessarily inherently better at accumulating capital than science, but that its application makes it more conducive to generating capital in modern capitalist societies. That said, it is clear from most accounts of the discovery of the structure of DNA, there were financial and funding constraints imposed on both Crick and Watson. See Strathern (1997) for a brief history of how funding factors affected the discovery of DNA.

[15] The salience of this point stems precisely from concerns with the role of biotechnology in society. Whilst it is argued in **Chapter 1** that this thesis aims to look at how biotechnology comes about, it nevertheless needs to be recognised that the socio-economic effects of biotechnology are important issues in themselves. Evidently, one of the most important aspects that needs to be borne in mind in this thesis is whether, when thinking about socio-economic effects, assumptions about the technology are made. From a cursory glance at the literature on biotechnology it becomes apparent that much of the work looking at its socio-economic effects makes such assumptions. For example, the CEC's (Thomas, 1993) forecast on the impact of biotechnology in the world is based on potential applications of rDNA technology; the actual technological developments are somewhat ignored. As a final point, one director of a biotechnology trade industry in Denmark believed that 'there were more people studying about biotechnology than actually doing it'. By this, I believe he is referring to the fact there is a considerable amount of hype and interest associated with biotechnology.

But such descriptions of science and technology elide the interaction that takes place between them. Despite the strong distinctions emerging from the research about science and technology, it is equally clear that they are connected. There are many views among the interviewees on how science and technology interact with each other. One view centres on definitions, with science and technology being treated as two ends of a scale:

> "There is a very fluid scale. There is pure science where you don't care about application, there is pure technology where you only go for your application, and there is a large area in-between...it is all on one scale there is pure science on one side and technology and techniques on the other side....that was the thing with biotechnology or genetic engineering, it was one of the first instances where something coming from this part of science could actually be used for a technology...." HB, Secretary, Advisory Committee on Genetic Modification, Ministry of Environment, The Netherlands

Leaving aside the soft distinction between science and technology, science and technology appear to be connected. More pointedly, whilst scientific and technological knowledge and activities may be construed as different, in biotechnology they are nevertheless connected with each other. But if there is a sense that science and technology are inextricably linked, it remains to be seen what the nature of these links are. In trying to ascertain the precise nature of the links between science and technology a typical response from the research is:

> "I would regard science...that is a hard one actually....I would regard science as when you break new ground when you find new things that haven't been known, you don't apply anything. Technology is more the application of the results of science and then the technology is when you add to the original science base of components which make it into a workable system....Science leads technology...." RR, Head of Technical Operations, Firm D, The Netherlands

Despite the difficulty in answering this question, in its crudest interpretation, the creation of knowledge associated with biotechnology follows a linear path. That is, developments in broader scientific understandings are transferred to specific applications via technology.

But whilst this linear model of the production of knowledge is cited by a number of other interviewees, and mirrors a more general tendency in conceptualisations of innovation as highlighted in **Section 2.2**, on a practical level, there are some uncertainties with it:

> "The science must be the development of the technologies. Forty years ago it was discovered that you had a DNA molecule. Twenty years ago we had the first successful genetic manipulation. So there has been a lot of basic work on what are genes and how they work, and how we can identify them and put them into new organisms....So research is about how the technology and science develop together." BN, Advisor on Biotechnology, Agricultural Council, Denmark

Thus a more complex set of relations in biotechnology are identified in biotechnological innovation. Whilst the linear model is evoked initially, the interviewee goes on to talk about the production of knowledge in biotechnological innovation in more recursive terms.

Given the overall evidence to suggest that science and technology are viewed, and therefore treated, as different and distinct activities, it seems reasonable to question the basis of technoscience. Under the circumstances described above, through looking at the production of knowledge it seems more appropriate to consider the relationship between science and technology not in terms of a total fusion but rather as a partial symbiosis. Put another way, whilst science and technology are clearly seen to interact with each other, from the research there are certain conditions that ensure that some distinction or difference is maintained. What arises out of their connection can be represented by the hyphenated 'techno-science'. For biotechnological innovation, the hyphenated techno-science is significant in two respects. Firstly, and echoing the debate about the multi-/inter-disciplinary nature of biotechnology, there are problems in bringing 'science' and 'technology' together. Secondly, there is a blurring of boundaries between science and technology as knowledge and as activities associated with the production of this knowledge. The ambiguities explicit in the hyphenated techno-science also find expression in the reflexivity of biotechnological knowledge.

7.5 Reflexivity in biotechnological knowledge

The tensions and ambiguities associated with bringing 'science' and 'technology' together in techno-science mask a third feature of the production of knowledge associated with biotechnological innovation, namely its 'reflexivity'. Giddens (1990) and Beck (1992) have explored the issue of reflexivity in terms of the emergence of a 'risk society', which refers to the stage of radicalised high

modernity reached in modern capitalist societies (Kumar, 1995:142; Adam, 1996:85). Whilst there are several differences in their approach - Beck focuses more on the societal level, whereas Giddens' main concern is with the individual - they both suggest that modern capitalist societies are now having to take stock of themselves. Consequently, modern societies experience reflexivity which entails greater socio-economic and political interactions between actors and individuals which filter through to the way techno-science constructs and tackles problems. The production of knowledge around techno-science, then, is shaped by a more diverse set of 'social' and 'technological' conditions and factors, and techno-science is viewed as more socially accountable (Levidow, 1996).

Although there are many features to the reflexivity of biotechnological knowledge, most are rooted to societal concerns surrounding the manipulation and use of DNA:

> "Some consumers do not agree with the technology (biotechnology) and there are two reasons why. I think one is because they are concerned about the safety. They are saying we don't know enough about the safety to prove that these things are safe. And on the other hand there's a view that says we don't like the idea of genetic modification because it is tinkering with the very stuff of life. So there is an ethical concern as well." CL, Committee Secretary, FAC, MAFF, UK

This interviewee highlights two aspects of concern with biotechnological innovation - safety and ethics. These elements are expressed by other interviewees. On the safety aspect of biotechnology, for instance, in the area of the agro-food systems one person makes the following point:

> "The tomato is a biological thing. Tomatoes contain small seeds and they go directly through your system....You cannot feel a gene. The problem is if you have living material or living bacteria like in tomatoes they could colonise a wider system or the environment....You don't want genes to spread out." BC, Programme Manager, Research, Ministry of Agriculture, Denmark

Whilst there is much debate about the danger of 'rogue genes' spreading uncontrollably to other species of plants and animals, this issue is largely theoretical as little research has gone into evaluating this kind of risk with biotechnology. Of course, it is important to recognise that accurate assessments about the long-term safety implications of (agro-food) biotechnology are difficult to ascertain given that the commercial development of many aspects of agro-food

biotechnology are slow in coming as highlighted in **Chapter 5**. Thus as a technical director in firm A notes, 'we can't predict what is going to happen in 50 years. I can't predict whether gene technology will affect us.'

Ethical concerns with biotechnology also have several dimensions. One dominant aspect which several interviewees mention centres on how biotechnological knowledge is used:

> "the application of biotechnology in human genetics and in food has major consequences...If you want, human genetics influences human dignity....there are ethical aspects to human genome research, such as whether to abort a child with defects." SC, Assistant Secretary, International Bioethics Committee, UNESCO, France (my translation)

This interviewee crudely expresses a common view throughout the literature (see **Section 7.2**) on how biotechnological knowledge, such as that covering the human genome, might be abused. In particular, the interviewee highlights the danger of constructing 'normality' in humans through eugenics. Another ethical concern is made by an interviewee working at the FAO and centres on the fact that 'there are social and political issues about who owns genetic resources and benefits from them.' Overall, then, there are a wide range of well defined elements to both the safety and ethical concerns linked to biotechnology.

But in many instances the concerns over genetic knowledge are less clear and systematic:

> "...you and I are probably frightened by biotechnology. And we've heard lots of scare stories about making new animals and blue tomatoes, and we don't really understand it. We don't know what it is and we've got every reason to be fearful at this stage. Until Joe Public is more comfortable with it, the uptake of biotechnology is going to be severely hampered." KB, Programme Manager, Biotechnology, Management Consultancy, UK

This view on consumers' opinions on biotechnology is not uncommon from the research (see **Section 6.3.4**). As well as strong evidence to suggest that consumers do not fully understand what biotechnology entails (CEC, 1997a), there is some sense from the research that the public have constructed particular images of biotechnology. Despite the perceived 'irrationality' of some consumer views on

biotechnological knowledge, the interviewee concedes that the public's perception may not be totally unreasonable as there remain serious ethical and safety concerns over the potential use of biotechnological knowledge.

Whether such views from the public are justifiable is a matter of debate. But it is clear that the picture of biotechnology presented to the public is mixed:

> "It is a scary technology for the layman. This has to do with the way biotechnology is pictured in the media. Also the scientists have made terrible mistakes when talking about biotechnology. They talk about cloned people, cloned animals; they talk about rabbits that look like goats, and cauliflowers that look like carrots, or things like that and all those stupid things....I also remember in the United States they developed micro-organisms which they spread on plants to prevent freezing, and when they did the first experiments, the people who were spraying this were dressed like astronauts. So you give an image to the people that biotechnology is a dangerous technology." HD, Policy Advisor, Ministry of Agriculture, The Netherlands

Leaving aside the specific role of the media in influencing techno-science, the power of the image of biotechnological knowledge cannot be underestimated. Whilst **Chapter 5** has shown discrepancies between actual and potential developments in agro-food biotechnology, particular views about the production of knowledge are influenced strongly by developments with transgenic animals:[16]

> "There is a lot of hysteria around these developments in biotechnology. For instance we had this famous bull, 'Hermann de Steer', in Holland. The science behind this is, of course, wonderful. If you can have such a production system for very specific chemicals it is ideal. On the other hand, you are changing something in such an animal....of which you may not be able to see all the consequences. On the other hand, when you talk about for instance genetically modified plants in which you build a certain disease resistance I cannot see how anybody could be harmed from that because this plant is in fact unchanged only it is, there is some additional protein, harmless protein for humans but which gives the plants a certain resistance against diseases or against insects which enables you to increase the crop enormously." MO, Research Manager, Firm C, The Netherlands

The discrepancy in the view in genetic modification between animals and plants coincides with earlier evidence that the public are more likely to accept the application of rDNA technology in plants (see **Section 5.2.1**). Nevertheless, what

[16] The possibility of human cloning has naturally been a catalyst for many of the debates about concerns with biotechnological knowledge. But as yet there is little evidence to suggest that it would be successful.

comes out of the research is a clear sense that biotechnological knowledge touches upon questions on what constitutes life:

> "Biotechnology is a technology that comes close to life. Borders between species are gone....I think we come very near to life and that threatens people." LH, Programme Manager, Biotechnology, Foundation for Public Information, The Netherlands

The most explicit point emerging from the three quotes above is that the nature of biotechnological knowledge concerns the public. This growing concern and unease with biotechnological knowledge - regardless of whether they are justified - shapes the production of knowledge. Put differently, these views are incorporated into the broader process of knowledge production.

These various views about the safety and ethical aspects of biotechnology are a dominant feature of the way knowledge is produced in biotechnological innovation. But much of this rhetoric about public concerns hides the deep significance of 'reflexivity' of biotechnological knowledge. From the stories of biotechnological innovation outlined in **Section 6.3**, biotechnological innovation appears socially accountable as diverse sets of actors and individuals influence, and are influenced by, the process. In particular, the linear model of communication in techno-science, from techno-scientists to the public, is changing as there is more of a dialogue. This dialogue is also reflected in models of innovation (see **Section 6.4**). This change in the nature of communication and debate about techno-science is indicative of the reflexivity of biotechnological knowledge.

Reflexivity is not an abstract feature of biotechnological innovation. It has some concrete manifestations. In the case of the public, for instance, actors involved directly in biotechnological innovation are influenced in the following way:

> "If you go into a supermarket and say is this cheese made from rennet in Britain?' it will filter back straight to the manufacturer who will say that we don't want that because of the treatment of BSE....The same is true in biotechnology." HP, Production Manager, Firm A, Denmark

As well as supporting an earlier observation on the importance of food retailers in presenting the consumer voice (see **Section 6.3.5**), this interviewee highlights

further the more socially accountable nature of knowledge associated with (agro-food) biotechnology. Additionally, social accountability of biotechnological knowledge is highlighted by the regulatory system:

> " I think consumers do influence us...we get a steady stream of correspondence and inquiries which we obviously can't ignore and makes us aware that there are views that are different to those expressed in the policy area and from the recommendations of committees. And the Committee (FAC) is certainly aware of that as well. So I think consumers do influence...we are aware of consumers' views and where necessary we go out and commission surveys as well as to see the spread of views....We have representatives who are specifically there because of their experience in working for consumer organisations....It is not in the industry's interest to ignore the consumer point of view." CL, Committee Secretary, FAC, MAFF, UK

The production of knowledge associated with biotechnological innovation emerges out of constant negotiations - in this case between regulatory institutions and the public. Biotechnological knowledge, therefore, is seen to emerge from a broader range of considerations.

Unsurprisingly, as shown in **Section 6.3**, biotechnological innovation concerns many 'political' interests:

> "Biotechnology is so controversial it (Government) has to make a political decision about it....It has to do with life...you are going into genes and changing them...you now have transgenic animals." LH, Programme Manager, Biotechnology, Ministry of Research, Denmark

Leaving aside the specific nature of the Danish context which leads to particular developments in the regulatory field (see **Section 6.3.4**), the manipulation and use of genetic knowledge has increasingly become a political issue. But many interviewees express concern over the narrow focus of political interest in biotechnology:

> "Biotechnology has been a political issue on a negative side and ethical side, you see with the bull Hermann. And you see a lot of politicians anxious, eager to discuss the ethical side to this knowledge...we had the discussion on biosafety and patenting, the same topics you will find in the European Parliament....So it was never a question of we are doing less biotechnology...there is no political movement to back biotechnology." MH, Programme Manager, Biotechnology, MEA, The Netherlands

Whilst these two quotes point to the involvement of political interest in the production of genetic knowledge it is clear that this involvement is considerably circumscribed. Despite this qualification, biotechnology has encouraged the greater politicisation of the 'production of knowledge' as it is increasingly an issue which is discussed by politicians.

It is hard to be precise over any time-scale of the reflexivity of knowledge production. But according to many interviewees it is a relatively new phenomenon:

> "I think the major change in the last 5-10 years is that researchers are being more involved with aspects and the ideas about society. So research is now not normless or without ethics...The major changes is that to start with biotechnology was only discussed among scientists, and government and research labs of industry. And later the non-government organisations are involved." AN, Programme Manager, Biotechnology, Ministry of Agriculture, The Netherlands

Another practical implication of this increased reflexivity is noted by a communications manager in DGXII of the CEC, 'we will have to be more conscious of industrial and societal needs in our programmes.' Indeed, this need for greater social accountability seems to be at the forefront of changes taking place in the promotion of biotechnology at a European level (see **Section 6.3.3**):

> "Biotechnology is different in relation to the Fifth Framework Programme in a sense...all these individual specific programmes in biotechnology will disappear, there will be something called 'Life Sciences'. The programme will be geared towards the consumer, the European consumer....The idea of Cresson,[17] which I think is quite good, it is a huge task but her philosophy is to try and educate and incorporate the European consumer about science." CM, Programme Manager, Biotechnology and Agriculture, DGXII, CEC, Belgium

There is clearly some ideological basis to these last two quotes as policy makers often believe that such multi-/inter-disciplinary approaches will speed up the process of innovation (see **Section 7.2**). Nevertheless, innovation policy in 'biotechnology' is trying to foster institutional arrangements that encourage the need to take into account a wider set of interests and conditions.

Greater reflexivity in biotechnological knowledge is shown in the examples and evidence presented above. But there is a danger of viewing 'reflexivity' as a

[17] The Director-General of DGXII (Research and Development) at the CEC.

consequence of developments in the production of knowledge. From the research, there is evidence to suggest that reflexivity associated with biotechnological knowledge also shapes aspects of modern capitalist societies.[18] As well as an increased sense of social accountability attached to the production of biotechnological knowledge, reflexivity also encourages new and distinct sets of practices. For example, new sorts of social arrangements around knowledge are emerging:

> "There are new collaborations where...we discuss gene technology...issues in relations to politics, consumers and industry....A common platform is emerging on biotechnology from which to work on." JS, Research Secretary, Firm A, Denmark

There is a danger of exaggerating the significance of these new arrangements. But biotechnological knowledge - both its nature and how it is produced - encourages, indeed necessitates, a widespread dialogue between various interests. Whilst problems with forging a multi-/inter-disciplinary approach in biotechnology have been shown in **Section 7.3**, certain social arrangements around biotechnology are emerging which are breaking, or at least extending, traditional means of communication in the production of knowledge. Indeed, institutional arrangements, such as the Office for Technological Assessment in the US, are being proposed which link, for instance, the social and natural sciences.[19]

There are also signs that the reflexivity associated with biotechnological knowledge may be linked to new forms of dialogue:

> "People are becoming more familiar with discussion on biotechnology. We are becoming more intellectual...even in schools we discuss these things...my parents did not discuss these things." MH, Member of Parliament and Chairwoman of Scientific Committee, The Netherlands

---

[18] Superficially, the evidence points to the importance of non-economic factors influencing the production of knowledge in biotechnological innovation, a view which corresponds with the more general account of biotechnological innovation given in **Chapter 6**.

[19] More recently, Monsanto, the multinational agro-food biotechnology company, has been involved in a publicity campaign to promote biotechnology. Interestingly, it provides details of organisations that are against biotechnology so that consumers can 'explore all the other points of view' (Ramsay, 1998). Whether this is an example of good public relations is a matter of debate; suffice to note that this is a relatively new dimension in information campaigns.

This interviewee points to the changing nature of discussion over time as there is now a debate about the position and role of techno-science in society. Such debates, brought about by the increased social accountability of biotechnology, are not problem-free. According to a research manager at the Office for Science and Technology in the Netherlands, 'rDNA was a very political issue, but Parliament was a bit embarrassed about it, they didn't really know how to deal with social and ethical aspects.' Nevertheless, biotechnology is raising the debate about knowledge production in techno-science to different groups and levels in society.

Superficially, these new forms of institutions and dialogue around biotechnological knowledge may also be leading to new forms of social action:

> "...pressure groups are very powerful. Look at Unilever they were probably into modern biotechnology and what a wonderful thing it was until Greenpeace went out and camped out on Guy Walkers' front lawn, and then suddenly it wasn't such a good idea. And we have seen Nestle and Unilever in Europe back down and throw away stuff...there is no rationale behind it." TW, Technical Director, Bread Improver Company, UK

Several interviewees made the point that biotechnology appears to be encouraging certain forms of 'anti-social' behaviour. Although debatable whether this is particularly new - there have often been protests against science and technology through the course of history[20] - according to a number of interviewees these forms of social behaviour seem to be particular to biotechnology and a relatively new phenomenon.

But perhaps the most important observation about the reflexivity of biotechnological knowledge from the research is the notion that it is forcing changes in the way people view the world:

> "...biotechnology is a sort of loss of innocence. All the sorts of biblical metaphors about eating the apple of the tree of knowledge are just as applicable as Galileo shifting the earth from the centre of the medieval universe of a flat earth society. So in a sense it (biotechnology) is as fundamental as Galileo and Darwin. James Burke the BBC television presenter and science presenter wrote a book called 'The Day the Universe Change'. Well it is a sort of play with words, it is not the universe that has changed, it is man's (sic.) perception of the universe." MC, Senior Advisor, Biotechnology, OECD, Paris

[20] Such as the Luddites' protest against the use of the knitting frame (Derry and Williams, 1970:289).

To summarise, from the discussion above, two points are important on the reflexivity of biotechnological knowledge and the way it is produced. Biotechnological knowledge is clearly socially accountable as a range of actors and interests are involved in its production. Whether this can be put down to the particular nature of knowledge about the gene is a matter of debate, but the epistemological status of knowledge seems to be changing with biotechnology. Secondly, and linked to a theme developing in the previous two sections, the reflexivity of biotechnological knowledge is not only a result of developments in techno-science but also shapes it.

7.6 Discussion

The explorations of multi-/inter-disciplinarity, the emergence of techno-science, and reflexivity, offer particular insights into aspects of knowledge and knowledge production characterising biotechnological innovation. In particular, in increasing an understanding of the nature of biotechnological innovation, this chapter aims to consider whether it is qualitatively different from other developments in techno-science. It is contended that biotechnology is a particular type of knowledge and the networks of biotechnological innovation reflect a particular type of knowledge production. From the evidence and discussion above, six key observations about knowledge in innovation in (agro-food) biotechnology can be made. The first is perhaps obvious but worth re-emphasising briefly: the production of knowledge associated with biotechnological innovation cannot be separated from the 'social' and 'technological' factors described in **Chapter 6**. This dimension is illustrated in the 'rise and fall' of the CUBE as political factors were central in bringing about its demise. This study, therefore, demonstrates further that the nature of biotechnological innovation - whether in terms of a model of knowledge or more generally - covers a range of actors, activities and conditions. Crucially, as manifested through its reflexive nature, biotechnological knowledge is as much 'techno-scientific' as it is 'social'.

Second, the problems with trying to combine different areas of knowledge through encouraging multi-/inter-disciplinary approaches and the difficulty in

linking 'science' and 'technology' together (as represented by the hyphenated techno-science), raises questions over the precise nature of biotechnological knowledge. From the research it seems more useful to think of biotechnology as a less coherent body of knowledge and more like a disparate collection of knowledges. These knowledges tend to exist independently from each other, maintained through particular socio-economic arrangements, and connect in biotechnological innovation under specific conditions. This notion fits into the uncertainty with the term 'biotechnology' identified in **Chapter 5**, as the multiple uses of the term point to a diverse range of contrasting and different knowledges partially linked together, thus making knowledge a flexible aspect of biotechnology. Moreover, the idea that various knowledges associated with biotechnology are only loosely connected by an appreciation of the gene can be linked to the nature and characteristics of the networks of biotechnological innovation described in **Chapter 6**, as they also tend to be disjointed.

Third, because of the problems and tensions related to bringing knowledges together, the production of knowledge in biotechnological innovation does not display any simple linear logic. There are clearly cumulative aspects of the knowledges associated with biotechnology. For example, as shown in **Section 6.3.2**, the time taken to clone host organisms for the manufacture of GMEs decreased dramatically through a combination of more experience with rDNA technology and increased knowledge about the manipulation of genes in organisms. But at the same time, the connection between knowledge about genes and the cloning of host organisms is not uni-directional. This multi-directional feature of knowledge in biotechnology is explicitly found in relations between 'science' and 'technology'. Despite the continuing persistence of the view that 'technology is applied science', and the logical assumption that 'technological developments emerge from scientific knowledge', the research highlights sufficient ambiguity to question this model. Thus some 'scientific' developments associated with biotechnology did not originally have commercial objectives - the discovery of the structure of DNA, for example - but later spawned many commercial technologies. Moreover, 'technological' aspects also inform some of the 'scientific' aspects of biotechnological innovation; for instance, the development of PCR used to copy genes, has been employed to build new strands of DNA and increase the

understanding of how genomes work. It follows that the partial fusion between 'science' and 'technology' may be thought of as unstable and multi-faceted. And this feature of biotechnological knowledge may encourage reflexivity as it facilitates looser organisational and institutional frameworks. In one sense, at least, the linear model of technological innovation may be viewed as more prescriptive than descriptive for the production of biotechnological knowledges.

Fourth, this chapter highlights the need to think about biotechnology and biotechnological innovation as existing in a dialectical relationship. Obviously there are connections between them - generally from the literature the former may be considered as the result of the latter. But from the research it is clear that in many instances descriptions of what biotechnological knowledges entail also correspond to how they are conceived. For instance, often when interviewees discuss the multi/inter-disciplinary nature of biotechnology they also suggest that this is necessary for biotechnological innovation to be successful. Similarly, views about scientific and technological knowledges and activities are often superimposed on each other. Additionally, the reflexivity of biotechnological knowledges can be viewed as being both a cause and an effect as the knowledges shape and are shaped by the means by which they come about. This point suggests further that biotechnological innovation needs to be treated simultaneously as both an input and an output, supporting the notion that the arguments and examples presented in **Chapters 5** and **6**, are two interconnected aspects of the same phenomenon.

Fifth, the conceptualisation of biotechnological knowledges, and the means by which they are produced through the networks of innovation, assumes a particular epistemology. A standard positivistic epistemology can be found in Bacon's inductive method whereby broad universal principles can be derived from observed facts (see **Section 2.3**). Similarly, linear models of (technological) innovation point to an epistemology where universal principles often associated with 'science' can be applied to particular instances in 'technological' development (see **Section 2.2**). From this latter point of view, the understanding of the structure of DNA can be applied to specific instances, such as in the manufacture of GMEs (see **Section 6.2**). But from some of the evidence in this chapter, a rather more complex picture of epistemology emerges. For instance, many of the 'universal'

principles in biotechnology exist separately and often in opposition to each other. Chemists and biologists engaged in biotechnological innovation work from very different units of analysis - the molecule and the cell respectively - which encourage different 'world views' on what and how knowledges are created and transformed. Possible tensions associated with these different 'world views' may be compounded further when different approaches from the natural and social sciences are integrated. Similarly, the reflexivity of biotechnological knowledges challenges the linearity associated with dominant epistemologies as there are multiple links between 'universal' principles and particular technological developments. In epistemological terms, then, the emergence of conflicting and contradictory processes poses challenges to the development and maintenance of a consistent framework of knowledge which is necessary if biotechnology is to be deployed astutely in socio-economic and political terms.

Sixth, the examples and arguments discussed on the production of knowledge can also be linked to a particular theory of ontology. For instance, the strong tendency among interviewees to suggest that 'science leads technology' can be rooted in the ontological priority the former has been given over the latter in modern capitalist societies. As outlined in **Section 2.3**, modern capitalist societies display a priority of theory over praxis. What is perceived or experienced is considered to be on a lower scale than what comes about conceptually. Taking the description of science-technology relations, it is possible to suggest that this has a deeper ontological basis represented by a theory/praxis dichotomy. Whilst the ontological basis of biotechnological innovation is considered further in **Chapter 8**, it is worth suggesting that the ambiguities and contradictions associated with the production of knowledge may have some ontological basis.

In aggregate, these six points on knowledge(s) and knowledge(s) creation associated with biotechnological innovation provide further information about the nature and characteristics of innovation in (agro-food) biotechnology. The main reason for looking at the production of knowledges associated with innovation in (agro-food) biotechnology is to examine whether it is qualitatively different from other developments in techno-science. Whilst generally difficult to test this empirically, evidence can be used to reveal whether the production of knowledges

associated with biotechnological innovation follows certain patterns. Overall it is hard to see whether biotechnological innovation is distinct and different from other aspects of techno-science; a comparative study between, for example, IT and biotechnology may have been more useful for this end. But it is possible to assert that biotechnological innovation is associated with both old and new systems of knowledge(s) and knowledge(s) production as many familiar systems and institutions of knowledges production are being incorporated and combined with newer more flexible modes. This dual development is leading to, for instance, new R&D arrangements and more holistic solutions to particular problems. More profoundly, however, the production of knowledges associated with biotechnological innovation may be challenging the way we think of techno-science in society. In showing that biotechnological knowledges cannot be easily separated from the means by which they come about, this chapter raises some of the existential aspects of biotechnological innovation. Thus, as is considered in the next chapter, from an ontological point of view, biotechnology may be a qualitatively different aspect of techno-science.

From this chapter biotechnological innovation needs to be viewed as involving several (dis)connected layers of activities. It is about the interactions and connections between various 'social' and 'technological' aspects. Biotechnological innovation is also about theories of knowledge production and epistemology. And speculatively, biotechnological innovation can be thought to have existential overtones as it highlights the complex role of techno-science in modern capitalist societies. All these levels and dimensions are linked to each other and, therefore, the arguments and examples presented in **Chapters 5** and **6** can easily be connected as they represent different dimensions of the same phenomenon. The basic point, however, is simple: the various elements presented in the three empirical chapters in this thesis offer a complex and interesting perspective for viewing and examining (bio)technological innovation.

7.7 Summary

This chapter considers the main features of biotechnological innovation in terms of the production of knowledge(s), linking and developing the discussions in **Chapter 5** and **6**. The analysis is organised around three main themes. The first looks at the multi-/inter-disciplinary nature of biotechnological knowledges. The second looks at the creation of knowledges through the emergence of techno-science. The third considers the reflexive nature of biotechnological knowledges. This chapter highlights a number of features of the production of knowledges that help extend the conception and understanding of innovation in (agro-food) biotechnology presented in **Chapters 5** and **6**. One feature is the problem in trying to undertake multi-/inter-disciplinary research required for biotechnological innovation. Another is the only partial fusion taking place between science and technology in biotechnology, as represented by the hyphenated techno-science. A third feature suggests that biotechnological knowledges exhibit degrees of social accountability. And finally, biotechnological knowledges and the means by which they come about exist in a dialectical relationship. Taken together, these aspects of biotechnological knowledges highlight further the multi-stable, diverse and ambiguous sets of activities, actors and conditions associated with biotechnological innovation. The 'social', 'technological' and now 'epistemological' elements of biotechnological innovation described in the empirical chapters evoke certain existential issues. In the next and final chapter, the nature of biotechnological innovation is examined in relation to capitalism and ontology.

8

EPILOGUE

This thesis highlights the many aspects and complexities of biotechnological innovation. It illustrates the enormous discrepancy between current and potential developments in agro-food biotechnology. It makes evident the considerable uncertainty with the term and even idea of 'biotechnology', and that this has practical implications for the developmental trajectories of agro-food biotechnology. It establishes that there are intimate connections between 'social' and 'technological' factors in the process of biotechnological innovation, highlighting the existence of a broad 'innovation milieu'. It shows that the particular developmental trajectories of agro-food biotechnology are linked to the multi-stable. diverse and ambiguous sets of actors, activities and conditions which characterise biotechnological innovation. It points to a dialectical relationship between biotechnology and the means by which it comes about. And it highlights the distinct epistemologies emerging around biotechnological knowledges.

In undertaking this study of innovation in agro-food biotechnology, current models of innovation in techno-science have been challenged. As outlined in **Section 6.4**, this study proposes that biotechnological innovation needs to be thought of as recursive, multi-dimensional and messy. The interdependencies and tensions between the various 'social' and 'technological' factors point to the importance of temporary localised factors - public health problems (**Section 6.3.2**) or the activities of key charismatic individuals (**Section 6.3.3**), for instance - which become fixed and then predispose the context within which innovation takes place to a particular set of choices. Biotechnological innovation, then, needs to be thought of in more specific and contingent terms, with the innovation milieu being far broader and deeper than is currently recognised. Structural elements, however, remain crucial as in biotechnological innovation, they are (re)constituted in daily life practices. Finally, this thesis argues that (biotechnological) innovation needs to be viewed as both an output and an input as its cause and effect elements are intimately connected.

The complexities of biotechnological innovation, and the effects they have, raise important questions over the development of capitalism. This thesis is premised on the belief that innovation, and technological innovation specifically, are critical elements of the dynamic for change and development in modern capitalist societies (see **Sections 1.1, 2.2** and **2.4.1**). Biotechnology is potentially of strategic importance for modern capitalist societies in that it is viewed as a major element of techno-science affecting the accumulation of capital. But from the preceding chapters certain ambiguities with the accumulation of capital associated with biotechnology can be identified. For example, in **Section 5.2.6** a discrepancy between actual and potential developments in agro-food biotechnology is highlighted. Most of the major developments involve food processing aids and raw materials for food provision, with the majority of developments and benefits accruing to producers in agro-food systems with consumers unlikely to notice or experience any significant difference in their food supply in the near future. This discrepancy points to the difficulty in commercialising certain areas of agro-food biotechnology because of (in part) the complexity and contingency of the broader innovation milieu. A further ambiguity with the accumulation of capital affected by biotechnological innovation is highlighted in **Sections 6.3.4** and **6.3.6**, as the regulatory environment developing around biotechnological innovation points to a persistence in the divergence of interests between, for instance, industrial and consumer groups. Consequently, some regulatory developments - such as the labelling requirements of GM foods - have impacted negatively on the process of capital accumulation. The production of biotechnological knowledges also highlights certain ambiguities associated with the generation of capital. Whilst the production of biotechnological knowledges is viewed as a crucial aspect of the process of capital accumulation (see **Section 7.2**), as described in **Section 7.3**, there are many problems and tensions with bringing areas of knowledge together. This feature of the production of biotechnological knowledges not only casts doubts over the precise nature of knowledges associated with biotechnological innovation, but also over the possibilities of fusing 'science' and 'technology' necessary for the accumulation of capital (see **Section 7.4**).

The most obvious manifestation of the ambiguity with capital affecting biotechnological innovation are the problems with making profits. The decision between 'making or buying' GMEs described in **Section 6.3.7** may be viewed as a

simple strategy to maximise profits. But there is evidence from the research that points to mixed prospects for profitability with biotechnological innovation. Much of the commercial development in biotechnology is in the agro-food sector; agro-food biotechnology currently has a market value of ECU 23 billion, 58 percent of the total biotechnology sector (Europabio, 1997:10; see also **Sections 1.2** and **3.3**). And yet the figures for investment in biotechnology remain skewed; out of £494.6m invested by venture capital firms in the UK only 3.5 percent was in agro-food biotechnology while 33 percent was in medical/health firms (Davidson, 1997). There are clearly differences in public attitudes and acceptance towards the development and use of biotechnology in various industrial sectors (see **Section 5.2.1**), although they have not been examined to any great length in this thesis (see **Section 1.2**). What the research suggests, however, is that despite the relative lack of commercial products in medical/health biotechnology, investments in this sector disproportionately outweigh current levels of profit. In part, this situation can be explained by the view that there is a greater potential for profits in medial/health biotechnology in the long-term. But the evidence also suggests that investments in medical/health biotechnology may be encouraged by a strong regulatory framework which has been built up over a number of years and which offers stability to capital. By contrast, as described in **Section 6.3.4**, the regulatory framework around agro-food biotechnology - encouraged by contention over what it entails (see **Section 5.3.3**) - is developing in a rather piecemeal and fragmentary manner. Capital, therefore, appears to be caught up in a paradoxical situation in that whilst it is attracted towards the stability and long-term prospects of profits of the innovation milieu around the medical/heath sector, it is neglecting medium-term potential investments in the agro-food sector. More generally, there is a tension between actual and potential profits in biotechnology. As the large number of high profile fraud cases involving biotechnology testify - the recent accusations that the DBF, British Biotechnology, has been fixing results of its clinical trials (*Guardian*, 1998c), for instance - there are huge pressures to ensure profits accrue in biotechnology (see **Sections 5.3** and **7.3**). In contrast to common assumptions made about biotechnology and capital accumulation (see, for instance, Byé and Fonte, 1994; Fransman, et al., 1995; Roobeek, 1995; Callan, 1996; Rabinow, 1997), then, in its present form the ability to generate capital and produce a profit using biotechnological innovation faces many problems (Levidow, 1996; Buttel, 1998).

Despite some of the difficulties with the generation of capital associated with biotechnological innovation, some elements of capital nevertheless succeed. To repeat an earlier point made in **Section 2.2**, innovation is disruptive in the Schumpeterian sense of 'creative destruction' as it opens up some opportunities and closes others. For biotechnology, this 'creative destruction' is also a feature of capital accumulation as certain elements of techno-science are being developed and promoted at the expense of others. Interestingly, in the case of biotechnological innovation some of the obstacles to accumulation may be exploited by certain elements of capital. For example, **Section 6.3.3** highlights distinct institutional arrangements in the organisational geographies of biotechnological innovation, especially in terms of public-private relations. Whilst these arrangements may differ in particular cultural contexts - between nations, for instance (see **Section 6.4**) - and are encouraged by the 'reflexivity' of the innovation milieu (see **Section 7.5**), behind the proliferation of public and private links in research there is a sense that much of the work being conducted in public research is increasingly undertaken with commercial objectives in mind. As illustrated in **Section 6.3.3**, a considerable amount of public money has gone into biotechnological innovation, a situation encouraged by the multiple uses of the term 'biotechnology' (see **Section 5.3**). In the UK, for instance, the Government has recently announced an extra £1 billion for the research councils and higher education funding councils with a particular emphasis on the 'life sciences' (*Research Fortnight*, 1998). This move towards a greater public funding of biotechnology has been encouraged by certain industrial interests - through the Foresight programme, for instance - which emphasise biotechnology's strategic importance for the UK. At the same time, some industrial interests are developing institutional arrangements, such as SAA, with publicly funded research bodies to exploit them (Kenney, 1995; Blumenthal et al., 1996). It seems reasonable to suggest, therefore, that some of the obstacles to capital accumulation may be created by capital. For example, as part of a need for greater social accountability (see **Section 7.5**), the current Public Understanding of Science (PUS) movement, although undertakes many critical analyses of techno-science and biotechnology specifically, is still premised on the belief that techno-science needs to be promoted (Kealey, 1996).

A deeper set of issues is also raised in the empirical chapters. **Section 2.3** invokes the idea that techno-science needs to be viewed not only in 'social' and

'technological' terms but also existentially. Some sense of this wider aspect of biotechnological innovation is demonstrated in **Chapter 7** as biotechnological innovation assumes a particular epistemology. In this case, the contested nature of biotechnology (see **Section 5.3.3**) and the differentiated, fragmented and stratified nature of biotechnological innovation (see **Section 6.4**) pose challenges to the development and maintenance of a consistent framework of knowledge(s) necessary if biotechnology is to be deployed astutely in socio-economic and political terms. Whilst the two dimensions to biotechnological knowledge(s) - what they are and how they are produced - extend the analysis of biotechnological innovation in this thesis, they also point to the importance of thinking about the wider implications of techno-science. From the research, there is evidence to suggest that biotechnological innovation can also be considered as part of an existential exchange (see **Section 2.3**). Heidegger (1966, 1995) highlights the importance of thinking about the role of (bio)technology in 'enframing' and 'revealing' the world to us, remarking (1966:50) 'the power concealed in modern technology determined the relation of man (sic.) to that which exists'. Whilst technology takes on a wider meaning than either the techniques or devices associated with industrialism, or the method and attitudes associated with scientific rationalism, for Heidegger it needs to be seen as a contemporary mode of understanding or disclosing things which makes the first two aspects possible (Zimmerman, 1990: xiii; Cooper, 1996:50). Importantly, Heidegger asserts that the position of science and technology is characterised by the modern dichotomy between theory and praxis (Ihde, 1979:xxii; Dreyfus and Hall 1992:7), which manifests itself in terms of an ontological priority of science over technology (Heidegger, 1977; Mitchum, 1994:49-55). This theory/praxis dichotomy has many implications. From the research, it is possible to assert that the theory/praxis dichotomy may impact directly on capitalism and techno-science. For example, the difficulties in trying to fuse 'science' and 'technology' together in techno-science (see **Section 7.4**) and the more general problems in undertaking multi-/inter-disciplinary work (see **Section 7.3**) may be linked to the theory/praxis dichotomy itself as the dichotomy could hinder links. In one sense, then, the ontologies of modern capitalist societies impact upon capitalism generally.

The link between certain ontologies of modern capitalist societies and the nature of capitalism has a further dimension. Changes in the nature of capitalism encouraged by biotechnological innovation may, in turn, affect the nature of modern capitalist societies. Some sense of this dimension to biotechnological innovation emerges from the empirical findings. In **Section 5.4**, for instance, the uncertainty with the term 'biotechnology' runs against the necessary precision for the repeatability of techno-science, a major feature of capital accumulation. This lack of precision contributes to the undermining of the authority of techno-science, and points to a greater sense of contingency and uncertainty associated with modern capitalist societies. Furthermore, the difficulty in trying to regulate biotechnological innovation described in **Section 6.3.4,** highlights some of the problems the state faces in regulating aspects of economic activity. In fact, increasingly it is possible to argue that the role of the state is being challenged in its ability to regulate capitalism generally. Perhaps most importantly, certain developments in the production of biotechnological knowledges are challenging the links between techno-science to society (see **Section 7.6**). Broadly, changes in the nature of capitalism encouraged by biotechnological innovation appear to be leading to the reconfiguring of relations between humans and techno-science. For example, the epistemological framework developing around biotechnological knowledges described in **Chapter 7** is raising key ontological issues over how humans relate to their environment. A case in point is the transfer of genes across 'species' through gene modification (see **Section 3.2**) which is not only catalysing a range of complex emotions (see **Section 7.5**) but is also encouraging a debate over whether humans can be defined by their genes (see **Section 5.3.2**). In addition, the reconfiguring of relations between humans and techno-science can be linked to discussions over the emergence of 'cyborgs' (see, for example, Haraway, 1997; see also **Section 1.1**) and 'hybrids' (see, for example, Squier, 1998) as biotechnology is encouraging a blurring of boundaries between 'nature' and 'techno-science' (see **Section 5.3.2**). In this respect, biotechnological innovation can be treated as qualitatively different from other developments in techno-science as it raises fundamental questions about what it means to be human.

The highlighting of ontology to describe and explain the nature and characteristics of innovation in (agro-food) biotechnology has major implications for

the study of innovation and techno-science. More 'geographical' notions, however, can also be employed to highlight the importance of ontology to understanding biotechnological innovation. Superficially, ontological features of society may be viewed as having particular spatial boundaries which have different impacts upon biotechnological innovation. For instance, whilst Denmark and the Netherlands have experienced a critical dialogue over the development and application of biotechnology (see **Section 4.4**), the fundamental importance of the scientist-state role, central to their version of capitalist development, is not challenged and levels of trust remain high (see **Section 6.3.4**). In the US, by contrast, the development of biotechnological innovation is less problematic than in most countries, as the neo-Schumpeterian model of innovation remains dominant; innovation and technological innovation specifically are viewed as fundamental to socio-economic development and the basis of a 'successful' society (Zukin, 1991; Schoenberger, 1997). In the UK, however, the case may be different as the problems in consumer acceptance of (agro-food) biotechnology may be linked to a more profound ontological shift in the way techno-science is viewed and developing with capitalism.

In highlighting the different 'geographies' of the ontologies associated with biotechnological innovation, this thesis makes more explicit some of the comparative aspects of the research. Despite the international nature of biotechnological innovation identified and described in this thesis (see **Section 4.4**), no attempt has been made to analyse in detail the specific national contexts in which it takes place. As outlined in **Section 1.2**, this thesis employs the spatial form of the 'network' to overcome some of the limitations with existing studies of innovation to gain a greater understanding of the innovation milieu. Whilst some general comparative comments have been made between the innovation of enzymes X and Y in **Chapter 6**, comparisons between, for instance, Denmark and the Netherlands, have only been contextual (see **Sections 4.4** and **6.3**). But coming out of the research, certain 'geographies' of biotechnological innovation may be important for understanding innovation. For example, how biotechnology is conceived and interpreted may be influenced by particular national cultural contexts resulting in different ontologies of techno-science (see **Section 5.3.3**). Similarly, the role of the state in regulating biotechnological innovation may differ

in particular national contexts resulting in different and distinct synergies and relations between public and private interests being created (see **Section 6.4**). The research, therefore, suggests the usefulness of making more explicit the national cultural contexts in which biotechnological innovation takes place - the subject of a future research agenda (see below).

More generally, this thesis also highlights certain key spatialities implicated in the complexity of (bio)technological innovation. There are many types of spatialities, such as the local and national, which are central to (economic) geographical analysis. And these spatialities remain critical to examining the nature and characteristics of biotechnological innovation. For example, biotechnological innovation can be seen to constitute the classic 'high-tech' work space for economic geographers (cf. Howells, 1994; Massey, 1997). This study also draws attention to the importance of social and cultural spaces for technological innovation (cf. Lundvall et al., 1992; Gertler, 1995). Equally, it shows through networks that the social relations of biotechnological innovation influence, and are influenced by, particular spatialities of economic geography (cf. Lee, 1997; Simmie, 1997a). More pointedly, it highlights the combined processes of geographical centralisation (cf. Shotet, 1994; Swann and Prevezer, 1996) and spatial dispersion (cf. McElroy, 1996; Albrow, 1996) in (bio)technological innovation. The study also demonstrates the spatial variability associated with interconnectivities in the agro-food system (cf. Arce and Marsden, 1993; Byé and Fonte, 1994), and it re-emphasises the inherent spatialities of the process of capital accumulation (cf. Harvey, 1989; Herod, 1997). This thesis employs the 'network' concept to cut across and connect these dominant spatialities in (economic) geography.

But the use of networks does not go unqualified. The centrality of networks to the study of biotechnological innovation has already been made explicit through the development of perspectives from ANT both in conceptual and methodological terms (see **Sections 2.4.2** and **4.4**), and several general criticisms have been made (see **Sections 2.4.3** and **6.4**). One broader issue that needs to be (re)considered is whether there is anything more than networks? From the accounts of ANT (see **Section 2.4.3**), networks are the most important analytical unit of socio-economic phenomena. For some writers, the ubiquitous nature of networks is seen to bridge

the debates over structure and agency. But what is apparent from the research is that not all activities - the family histories of individuals involved in biotechnological innovation, for instance - are (easily) connected to the networks. Approaches in ANT offer a predominantly agent-centred analysis (Kleinman, 1998) and, in some respects, the networks neglect fundamental aspects of capitalism, such as the nature of capital itself. Thus, for (economic) geography, networks are problematic as although they allow certain categories and borders to be bridged, they run the risk of being reductionist. In this study, then, the use of networks has been more useful in methodological rather than theoretical terms.

It remains to speculate on how this study of innovation in agro-food biotechnology can be taken forward. Studies in techno-science are a rapidly changing area of considerable academic (and commercial) value, and one of the most innovative aspects of this thesis has been to adopt an approach for 'following' the actors to trace networks. Whilst the problems with this approach have already been highlighted in terms of how it is executed (see **Section 4.4**) and how it is described (see **Section 6.1**), there is clearly a need to analyse further the meaning and significance of 'actors' and 'networks' in (bio)technological innovation. For instance, the production, circulation and consumption of material objects that mediate the networks could be examined. Similarly, from a methodological stand-point it is worth considering whether the networks of innovation in agro-food biotechnology would have been different if the GMEs had been followed along a different route - from consumers to producers for instance? Additionally, whilst the account of biotechnological innovation in this research drew from a broad appreciation of ANT perspectives which avoided the specifically defined categories of the 'social' and the 'technological', it remains to be seen how networks can be identified and categorised in a simple systematic way which allows comparisons to be made, or generalisations to be drawn. Finally, and remaining on the methodological theme, there is the question of the particularities of the agro-food system and especially GMEs. How would the networks of biotechnological innovation look like if the main case studies were transgenic animals? And more broadly, what are the differences, if any, between the networks of innovation associated with agro-food systems and those that might be connected to health care?

Following this, it is clear that future work needs to think about ways to illuminate the interactions of the multiple dimensions of biotechnological innovation. In theoretical terms, it is important to think about how structural and agency dimensions can be incorporated into the form of network analysis employed here. Moreover, the importance of epistemological questions for the study of biotechnological innovation also needs to be recognised. If we are experiencing the development of a 'new' techno-economic paradigm built around biotechnology, why have particular knowledges and expertise centred on an understanding of the gene - the transfer of genes between species, for instance - moulded together or attained increasing weight in modern capitalist societies. More especially, in the new 'bio-information age', why have biotechnological knowledges become especially interesting or important? Similarly how are notions of 'nature' and 'society' constructed in modern capitalist societies, and how do they interact with each other in techno-science? Since consumers seem to be reluctant to accept the use of rDNA technology in the provision of food, is the apparent tension between the 'bio' and the 'technology' in biotechnology deeply embedded in our society, and how does this affect innovation? Or even, is biotechnology a valid epistemological or ontological category? Furthermore, how are the evolving relationships between, for example, the state and the market to be conceptualised? Are they, as actor-network theorists would have us believe, also to be considered as networks which link particular processes together or do new spatial forms have to be identified and developed? In a different vein, why are there persistent problems with linking science and technology together? Further appreciation of all the facets of techno-science in modern capitalist society needs to be undertaken which deepens notions that link socio-economic activities, such as innovation, to how they are experienced. In particular, what is the precise nature of capital associated with biotechnological innovation and is there empirical evidence to suggest that biotechnology is qualitatively different from other elements of techno-science? Finally, what are the specific changes in the ontologies of capitalism and society, and what is the nature of relations between them?

Perhaps the biggest challenge emerging from this thesis, though, is moving this study beyond academic life. There is an obvious need - given the motivations of this research (see **Section 4.2**) - to think more about how understandings of

biotechnological innovation and techno-science can be interpreted and translated into means by which they are used for the benefit of all. What will a study of biotechnological innovation tell us about how actors such as the state can (and should) influence the developmental trajectories of these technologies? What sort of technological infrastructure can be developed which will support (bio)technological innovation effectively? More specifically, given some of the tensions and problems with the developing regulatory framework, how can the interests of consumers be combined with industrial needs in the biotechnology sector? Furthermore, given there are no universal technologies, how have the different contexts - cultural, environmental, consumer, for instance - influenced the innovations that have emerged and how might they be developed to impact upon the diffusion of biotechnology? Finally, how can a study in techno-science contribute to a general understanding of (high, late, post?) modernity?

This thesis is rich in suggestions about the future direction of work on biotechnological innovation, specific in the evidence that has been presented, and grounded in the complex discussion of the development of techno-science in late 20th century modern capitalist societies. In an obvious way, these points provide a guide to future possibilities of research even though no claim is made that this is a definitive list of future questions or topics to be examined around biotechnological innovation. Above all, this thesis has hopefully highlighted the centrality of techno-science to human society.

One final point should perhaps be made. In seeking to undertake an in-depth investigation of innovation in agro-food biotechnology, this research project has involved an iterative process with existing texts, literatures, knowledges and, of course, key actors and individuals. In one sense, at least, the undertaking of this research project has been part of the existential exchange which, to use Heideggerian terminology, has 'revealed' the world to us. This thesis, therefore, is part of the networks of biotechnological innovation. To this extent, it 'is' techno-science.

APPENDIX A

Survey

This appendix contains an example of (i) letter used to introduce the survey, and (ii) the postal questionnaire (reduced size) used to examine innovation in agro-food biotechnology. See **Chapter 4** for further details of their use.

Kemal Ahson
Department of Geography
University College London
26 Bedford Way
London WC1H 0AP
☎: (+44) 0171-637 0540
Fax: (+44) 0171-380 7565
email: kahson@geog.ucl.ac.uk

10/1/96

Name
Name and address of firm

Dear xxxxxx

Re: Innovation in (Agri-Food) Biotechnology

Following a conversation with one of your colleagues about my study of innovation in biotechnology, I enclose two questionnaires:

1. To be completed by a **senior manager** who is, or has been, involved (indirectly) with biotechnology research and development (R&D).

2. To be completed by a **research scientist** currently working on such R&D.

The enquiry forms the basis of my doctoral research funded by the Economic and Social Research Council (UK). Our current understanding of the actors, sites, and processes involved in innovation in biotechnology remains limited, and this study hopes to contribute to improving our knowledge of this crucial activity.

In spite of the complexity of the issues, I would hope that the questionnaires would take no more than 15 minutes to complete. All responses will, of course, be treated in strictest confidence and individual companies will not be identified. Analysis will be at an aggregate level and data used for academic research purposes only.

The work clearly depends on the responses to this enquiry, and I am most grateful for the time you and your colleagues may spend in responding to it. It would be most helpful if the questionnaires could be returned, using the pre-paid envelopes, by the end of February.

If you have any questions or comments please do not hesitate to contact me.

Yours sincerely

Department of Geography
University College London
26 Bedford Way
London WC1H 0AP
☎: 0171 380 7050
Fax: 0171 380 7565

INNOVATION IN AGRI-FOOD BIOTECHNOLOGY

Questionnaire

Instructions for the completion of the questionnaire

Please answer each question by ticking the box(es) opposite your preferred response(s) or by writing in your answer when asked to do so. You may tick as many boxes to each question as you like unless otherwise specified. Instructions are given where further action is required. The questionnaire should take no more than 10 minutes.

The questionnaire is divided into 3 sections

SECTION 1: YOU AND YOUR ORGANISATION
In this first section we ask you questions about you and your organisations' activities.

SECTION 2: AGRI-FOOD BIOTECHNOLOGY
This section seeks to establish you and your organisations' involvement in agri-food biotechnology R&D

SECTION 3: RESEARCH & DEVELOPMENT
In this section we ask you to describe your organisation's involvement in agri-food biotechnology R&D

ALL RESPONSES WILL BE TREATED IN STRICTEST CONFIDENCE AND WILL BE USED FOR ACADEMIC RESEARCH PURPOSES ONLY

This research is supported by the Economic and Social Research Council (Award No. R00429534003)

SECTION 1: YOU AND YOUR ORGANISATION

1. What is the name of your company/organisation?

2. What is your name and job title/position (eg. Chief Scientist, Product Manager, Senior Manager etc.)?

Name: Job title/position:

3. How would you classify the central activity of your company/organisation?

☐1 Academic R & D	☐2 Commercial R & D	☐3 Petro-Chemical industry
☐4 Agriculture	☐5 Food manufacturing	☐6 Feed manufacturing
☐7 Food retailing	☐8 Financing	☐9 Government agency
☐10 Management Consultancy	☐11 Legal consultancy	☐12 Regulation
☐13 Trade lobby	☐14 Other (please specify)	

4. What areas of biotechnology are your company/organisation involved in?

☐1 Food	☐2 Feed	☐3 Plant agriculture
☐4 Additives	☐5 Animal agriculture	☐6 Processing aids
☐7 Chemicals	☐8 Human health care	☐9 Environmental control
☐10 Processing equipment	☐11 Research equipment	☐12 Other (please specify)

5. Which of the above areas is your company/organisation **primarily** involved in?

6. In what region(s) of the UK are your HQ and biotechnology R&D facilities located in?

	HQ	R&D		HQ	R&D
South East	☐1	☐2	South West	☐3	☐4
East Anglia	☐5	☐6	East Midlands	☐7	☐8
West Midlands	☐9	☐10	Wales	☐11	☐12
Yorkshire & Humberside	☐13	☐14	North West	☐15	☐16
North	☐17	☐18	Scotland	☐19	☐20
Northern Ireland	☐21	☐22			

7. Do you have any HQ/R&D facilities abroad?

☐ No (Please go to **Question 8**) ☐ Yes

If Yes, in which countries are these facilities located?

HQ: R&D:

8. When was your company/organisation formed?

9. What was the size of your company/organisation in terms of annual turnover and full time employees in 1994?

Annual turnover: Full time employees:

10. What percentage of your annual turnover in 1994 was directly linked to sales and R&D activities in biotechnology?

Sales: R&D:

11. What percentage of your biotechnology related sales are made to the following types of customers?

	Products	Services
Agriculture & Fisheries		
Food and Drink		
Chemicals		
Utilities		
NHS		
Professional & Scientific Services		
Mining		
Other (please specify)		
Total	100	100

SECTION 2: INVOLVEMENT IN AGRI-FOOD BIOTECHNOLOGY

1. Is your company/organisation involved in **any** capacity in the development and/or application of agri-food biotechnology?

☐ No (Please stop) ☐ Yes

If Yes, in which of the following areas is your organisation involved in?

☐$_1$ Food	☐$_2$ Feed	☐$_3$ Plant agriculture
☐$_4$ Additives	☐$_5$ Animal agriculture	☐$_6$ Processing aids
☐$_7$ Chemicals	☐$_8$ Human health care	☐$_9$ Environmental control
☐$_{10}$ Processing equipment	☐$_{11}$ Research equipment	☐$_{12}$ Other (please specify)

2. What is your **personal** involvement in agri-food biotechnology?

3. Which of the following sources (if any) do you use to keep informed about (agri-food) biotechnology?

☐$_1$ Academic background (please specify)	☐$_2$ Books
☐$_3$ Newspapers & Magazines	☐$_4$ Trade journals (please specify)
☐$_5$ Television/Radio	☐$_6$ Outside consultants
☐$_7$ Colleagues	☐$_8$ Lectures
☐$_9$ Conferences	☐$_{10}$ Industry associations (please specify)
☐$_{11}$ Government agency (please specify)	☐$_{12}$ Other (please specify)

4. Does your work involve informing others about (agri-food) biotechnology?

☐ No (Please go to **Question 5**) ☐ Yes

If Yes, who does this involve (eg. other organisations, other functions etc.)?

How do you inform them (eg. lectures/presentations, written memos, telephone etc.)?

5. When do you think *modern* biotechnology (genetic engineering techniques, rDNA, cell fusion etc.) will be widely used in the following products/processes in Britain (examples in brackets)?

	Now	In 2yrs	In 5yrs	D/K*	N/A
Raw material					
Production (in-vitro fertilization, solid-state fermentation)	☐1	☐2	☐3	☐4	☐5
Modification/improvement (bioconversion of polysaccharides)	☐1	☐2	☐3	☐4	☐5
Preservation (silage, coffee fermentation)	☐1	☐2	☐3	☐4	☐5
Identification/quality assessment (microbial methods)	☐1	☐2	☐3	☐4	☐5
Ingredients, production and processing aids					
Production (enzymes, vitamins, vanilla)	☐1	☐2	☐3	☐4	☐5
Modification/improvement (hydrolysis of proteins)	☐1	☐2	☐3	☐4	☐5
Preservation (immobilization of biocatalysts)	☐1	☐2	☐3	☐4	☐5
Identification/quality assessment (enzymatic and microbial methods)	☐1	☐2	☐3	☐4	☐5
Food material					
Production (bread)	☐1	☐2	☐3	☐4	☐5
Modification (meat tenderization)	☐1	☐2	☐3	☐4	☐5
Preservation (lactic acid fermentation)	☐1	☐2	☐3	☐4	☐5
Processing methods (enzymatic separation, fermentation)	☐1	☐2	☐3	☐4	☐5
Identification/quality assessment (microbial and biological methods, biosensors)	☐1	☐2	☐3	☐4	☐5
Waste material					
Improvement/modification (single-cell protein, vinegar)	☐1	☐2	☐3	☐4	☐5
Utilization (protein recovery)	☐1	☐2	☐3	☐4	☐5
Identification/quality assessment (enzymatic and microbial methods)	☐1	☐2	☐3	☐4	☐5
Environment					
Improvement/modification (air/water purification)	☐1	☐2	☐3	☐4	☐5
Preservation (soil preservation)	☐1	☐2	☐3	☐4	☐5
Identification/quality assessment (biosensors)	☐1	☐2	☐3	☐4	☐5

* D/K = Don't Know

6. In your opinion, what will be the most significant **developments** in the agro-food system brought about by *modern* biotechnology?

7. In your opinion, how important are the following factors for the **commercialisation** of *modern* agri-food biotechnology?

	Least important ⇒			Most important		D/K	N/A
Size of potential market (products/services)	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Strength of competition	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Price of competitive products/services	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Availability of finance	☐1	☐2	☐3	☐4	☐5	☐6	☐7
R&D costs	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Adequacy of intellectual property in the UK	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Adequacy of intellectual property in Europe	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Adequacy of intellectual property in the US	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Regulatory requirements in the UK	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Regulatory requirements in Europe	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Regulatory requirements in the US	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Consumer concern	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Availability of collaborators	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Government support	☐1	☐2	☐3	☐4	☐5	☐6	☐7

8. How important do you think the following **technologies** are for the development of *modern* (agri-food) biotechnology?

	Least important ⇒				Most important	D/K	N/A
Telecommunications	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Computers (Hardware)	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Computers (Software)	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Computer Aided Design	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Computer Aided Manufacturing	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Robotics	☐1	☐2	☐3	☐4	☐5	☐6	☐7
New Materials	☐1	☐2	☐3	☐4	☐5	☐6	☐7
Microchips	☐1	☐2	☐3	☐4	☐5	☐6	☐7

9. What other **technological** developments do you think will impact significantly on the development of *modern* (agri-food) biotechnology?

SECTION 3: RESEARCH & DEVELOPMENT

1. Are you and/or your organisation involved in agri-food biotechnology R&D?

☐ No (Please stop) ☐ Yes

If Yes, what form does this involvement take?

For you personally:

For your company/organisation:

2. What percentage of your company/organisation's agri-food biotechnology R&D is in the following areas?

Product development
Product/service improvement
Contract work
Other (please specify)
Total 100

3. Is your company/organisations' agri-food biotechnology R&D carried out *in-house*?

☐ No (Please go to **Question 9)** ☐ Yes

If Yes, what are the main reasons for this (please tick)?

☐1 Secrecy
☐2 Lack of partners
☐3 No need for partners
☐4 Historical
☐5 Geographical
☐6 Cost
☐7 Other (please specify)

4. Do you have a specific department for *in-house* R&D?

☐ No (Please go to **Question 5**) ☐ Yes

If Yes, what is the name department and how many people are employed in it?

Name of department:

Number of people employed:

5. Does the R&D process only involve technical/scientific staff?

☐ No ☐ Yes (Please go to **Question 6**)

If No, what are the backgrounds/departments of these other individuals?

6. How would you categorise the **structure** of your *in-house* R&D?

☐$_1$ Staff working on individual projects
☐$_2$ Small groups of individuals working on specific objects
☐$_3$ R&D department working on one major project
☐$_4$ Other (please specify)

7. How would you best describe the **initiation** of your *in-house* R&D?

8. How would you best describe the **management** of your *in-house* R&D?

9. Has agri-food biotechnology R&D been carried out with other companies/organisations?

☐ No (Please go to **Question 15**) ☐ Yes

If Yes, how would you describe the *inter-organisational* activity of the last three years (please complete table)

Key:-
Nature of co-operation: Joint ventures and research corporations (combinations of the economic interests of two organisations); Joint R&D (sharing of resources and joint development agreements); Technology exchange agreements (technology sharing agreements, cross-licensing, mutual second sourcing); Direct investment; Customer-supplier relations (contract mediated research); One-directional technology flows (second sourcing, licensing agreements)

Motivations for co-operation: Expansion/new markets, reductions of innovation lead time, technological complementarity, influencing market structure, rationalisation of production, monitoring of technological opportunities, basic R&D, lack of financial resources, high costs and risks

Partners (specify number & name)	Nature of co-operation	Motivations for co-operation
Academic		
Dedicated biotechnology firms		
Petro-chemical industry		
Food equipment/aids manufacturers		
Food manufacturers		
Retailers		
Government agency		
Farmers		
Consumer groups		
Others		

10. In your opinion, are there any forms of **informal** *inter-organisational* activity which influence the R&D process?

11. During *inter-organisational* R&D, what **departments** in your company/organisation are individuals drawn from?

12. How would you categorise the **structure** of your *inter-organisational* R&D?

$\square_1$ Staff working on individual projects
$\square_2$ Small groups of individuals working on specific objects
$\square_3$ R&D department working on one major project
$\square_4$ Other (please specify)

13. How would you best describe the **initiation** of your *inter-organisational* R&D?

14. How would you best describe the **management** of your *inter-organisational* R&D?

15. How important do you think the following actors are in **initiating** R&D in (agri-food) biotechnology?

	Least important ⇒			Most important		Don't Know
Academic R & D	$\square_1$	$\square_2$	$\square_3$	$\square_4$	$\square_5$	$\square_6$
Dedicated biotechnology firms	$\square_1$	$\square_2$	$\square_3$	$\square_4$	$\square_5$	$\square_6$
Petro-chemical industry	$\square_1$	$\square_2$	$\square_3$	$\square_4$	$\square_5$	$\square_6$
Food manufacturers	$\square_1$	$\square_2$	$\square_3$	$\square_4$	$\square_5$	$\square_6$
Retailers	$\square_1$	$\square_2$	$\square_3$	$\square_4$	$\square_5$	$\square_6$
Farmers	$\square_1$	$\square_2$	$\square_3$	$\square_4$	$\square_5$	$\square_6$
Government department (please specify)	$\square_1$	$\square_2$	$\square_3$	$\square_4$	$\square_5$	$\square_6$
Consumers	$\square_1$	$\square_2$	$\square_3$	$\square_4$	$\square_5$	$\square_6$
Other (please specify)	$\square_1$	$\square_2$	$\square_3$	$\square_4$	$\square_5$	$\square_6$

16. What changes (if any) have taken place in your company/organisation to make *in-house/inter-organisational* R&D more **efficient**?

17. What major improvements in the R&D process might make *in-house/inter-organisational* R&D more **effective**?

If you have any additional comments that you would like to make, please include them here.

Thank you very much for completing the questionnaire
Please return your questionnaire in the pre-paid envelope provided by the end of February

Printed by Central Services, University College London

APPENDIX B

Pilot study

This appendix contains an example of (i) the letter used to recruit research scientists for the pilot study, and (ii) a summary of the interview schedule used to organise the interviews. See **Section 4.4.1** for further details of their use.

Kemal Ahson
Department of Geography
University College London
26 Bedford Way
London WC1H 0AP
☎: (+44) 0171-637 0540
Fax: (+44) 0171-380 7565
email: kahson@geog.ucl.ac.uk

20/2/96

Name
Name and address of firm

Dear xxxxxx

Re: Study on innovation

I am a second year doctoral student examining innovation in agro-food biotechnology.

As part of my research, I aim to follow an enzyme - from enzyme manufacturer to final consumer - through the agro-food system, to get some idea of the actors, sites and mechanisms involved in the process of innovation.

Accordingly, I would like to conduct interviews with research scientists involved in the development of enzymes to ask them about: (1) how they go about the business of research and development; and (2) how they see the developmental trajectory, especially in enzymology, evolving. A more precise interview schedule is being compiled.

My research depends on the assistance of enzyme manufacturers, and I would be most grateful for the time you and your colleagues may spend in considering my request. All interviews will, of course, be treated in strictest confidence an individual companies and products will not be identified. Data will be used for academic research purposes only.

I intend to be in Denmark from 29 April to 11 May (1996) to conduct these interviews, and would greatly appreciate it if you could spare about an hour to be interviewed.

I look forward to the opportunity of discussing my request in the near future, and if you have any questions or comments please do not hesitate to contact me.

Yours sincerely

Interview Schedule

Name:
Organisation:
Place:
Date/Time:

1. Introduction
- objectives of (pilot) study

2. Background
- organisational profile
- individual profile

3. Developmental trajectory of biotechnology
- defining biotechnology
- importance of other disciplines/technologies
- major developments in (agro-food) biotechnology
- aims of modern biotechnology
- impact upon food provision

4. Research and development - the internal network
- organisational/personal involvement
- initiation and management of innovation
- mechanisms for interaction between different units and employees

5. Research and development - the external network
- links to the `outside' environment
- relations with users
- anticipating the needs of the market and society

6. Concluding issues

Kemal Ahson, April 1996

APPENDIX C

In-depth study of innovation of GMEs

This appendix contains examples of (i) an interview schedule used to organise the interviews for the in-depth study of innovation of GMEs for individuals 'directly' involved in innovation, and (ii) an interview schedule for individuals 'in-directly' involved in innovation. See **Section 4.4.2** for further details of their use.

INTERVIEW SCHEDULE: Phase II

INTRODUCTION

Thank you for agreeing to speak to me - as you know your name was passed on to me by _____ who said that you might be able to help me in my research. Before I continue I'd just like to say that this discussion will be **confidential** and that the information will be mainly used for my doctoral thesis.

As a quick introduction, I'm a third year doctoral student at UCL looking at biotechnological innovation across Europe. I'm interested in the individuals and the types of interactions and links involved in the innovation of GMEs and how they might differ across Europe. Broadly, I am arguing that R&D is more than a technological process; rather it is a social phenomenon. To focus my study I am concentrating on enzymes and in particular _____. **(NB. ESTABLISH ENZYME @ FIRST INTERVIEW).** From this I'm hoping to sketch out the innovation network.

I'd like to structure the discussion around 4 broad themes:

A. Agents and individuals
B. Ideas
C. Information and knowledge
D. Enzymes

I appreciate that you are busy and so this discussion should take about an hour. However to make my job easier do you mind if I tape the conversation? **(PREPARED FOR NO?)**

SWITCH BOTH CASSETTE AND MICROPHONE ON

> a transcript of the interview will be sent to you for comment

> do you have any questions?

GENERAL

(1) How would you define biotechnology?

(2) What are the main areas of knowledge or technology used in biotechnology?

(3) What do you think are going to be the major developments in biotechnology, especially through rDNA technology in the foreseeable future?

(4) How might they impact upon food provision?

(5) Do you think biotechnology is 'natural'?

A: ACTORS & INDIVIDUALS (GET NAMES INCLUDING UK)

(1) To begin with, could you say a few words about what your role in this organisation is and your involvement in developing _____ ?

(2) What is your relationship to (contact person)?

(3) Who (else) do you deal with directly during this project? (Get names - make appointments)

(4) Can you think of other people, both inside and outside this organisation who are important for this R&D project who you haven't dealt with directly?

(5) Can you think of any individuals or organisations who had a negative impact (held it up) on the R&D process?

(6) Do you have any contact with the public during this project?

(7) Have you noticed any changes in the types of organisations or people you have been involved with in the R&D process?

B: IDEAS

(1) Do you know where the idea for _____ came from?

(2) How did you translate this idea into a workable R&D project?

(3) Do you know whether competing ideas or methods were considered for _____? How did you choose between them?

(4) To what extent did past ideas or projects influence this one?

(5) Are there any ideas you have had which you haven't taken forward or used in your work ?

(6) Generally, do you think you get most of your ideas from 'experimenting' or 'thinking'?

(7) Were there any scientific/social concerns that you took into account when taking this idea forward?

(8) Are there any risks with rDNA technology ?

C: INFORMATION & KNOWLEDGE

(1) Do you think there is a difference between information and knowledge?

(2) What do you understand by 'practical' and 'theoretical' information/knowledge

(3) What types of information/knowledge were used when formulating this project (marketing, scientific, accounting etc.)?

(4) Did you produce any information/knowledge during this project?

(5) Are some types of information/knowledge more successful or useful than others in your work?

(6) Do you think there is a difference between 'science' and 'technology'?

(7) Generally speaking, what is the 'science' and 'technology' used in biotechnology?

(8) What was the 'science' and what was the 'technology' used in this project?

(9) Are there any differences of approach, or ways of seeing things, in biotechnology compared to other sciences/technologies?

D: ENZYMES

(1) What is an enzyme?

(2) What are the different stages of developing and producing an enzyme?

(3) How long did _____ take to develop?

(4) From your position, what and when were the main stumbling blocks during the R&D process?

(5) What 'instruments' and 'tools' do you use in your work?

(6) How do you think the R&D process could have been improved or made more efficient?

End (Arrange Further Interviews)

That brings me to the end of the interview

SWITCH CASSETTE AND MICROPHONE OFF

(1) Transcript

(2) You mentioned a couple of people in the interview who you work with? Do you think it would be possible for me to speak to them?

(3) Offering

(4) Contact
This is meant to be my last phase of interviews but if there is anything I need clarified would you mind if I contact you?

Kemal Ahson, 30 August 1996

Interview Schedule

Phase II (individuals 'in-directly' involved)

Name:
Organisation:
Place:
Date/Time:

Part A

1. What does this organisation/department do?

2. What do you do?

3. What is your organisation's involvement/interest in (agro-food) biotechnology?

4. What is your personal involvement/interest in (agro-food) biotechnology?

5. Why get involved? What factors influence this?

6. Do you think you influence R&D in (agro-food) biotechnology? How?

7. Generally speaking, what factors do you think influence developments in (agro-food) biotechnology?

8. Who are the main actors influencing R&D in agro-food biotechnology?

9. Have there been any changes in your involvement in (agro-food) biotechnology? How would you prescribe your future involvement?

Part B

1. How would you define biotechnology?

2. Is there a difference between science and technology?

3. What is the science and technology in biotechnology?

4. What are going to be the major developments in (agro-food) biotechnology?

5. How would you describe the R&D process?

6. How could the R&D process be improved?

7. What do you think are the main stumbling blocks in R&D?

8. Are there any risks with agro-food biotechnology?

9. Do you have any concerns about agro-food biotechnology?

10. How do you prescribe the future for biotechnology?

APPENDIX D

This appendix contains a list of all the interviewees that were involved in the pilot study and main research. Job descriptions are those provided by interviewees. Personal names are not given.

PILOT STUDY (Phase I)

Denmark (April 1996)

1. IA, Research Scientist, Research Institute
2. JN, Research Scientist and Director of Biotechnology Trade Organisation, University
3. JT, Consultant and Lobbyist
4. KJ, Research Scientist, National Research Laboratory
5. KP, Director, DBF
6. LC, Director, Biotechnology Stimulation and Investment Organisation
7. MH, Research Manager, Firm A
8. OD, Research Scientist, University
9. OT, Director, Biotechnology Information Company
10. PG, Senior Advisor, Ministry of Research
11. SR, Research Scientist, Multinational Brewery
12. TM, Research Scientist, National Research Laboratory

The Netherlands (May 1996)

13. AB, Research Manager, Multinational Chemical Company
14. AO, Director of Research, Multinational Fermentation Company
15. BK, Research Manager, DBF
16. BS, Head of Biotechnology, Multinational Chemical Company
17. KL, Scientific Director, Research School
18. ME, Research Director, Firm D
19. MH, Research Scientist, University
20. MO, Research Manager, Firm C
21. RB, Research Scientist Firm C
22. RM, Director, Biotechnology Industry Trade Association
23. RS, Professor of Biochemistry and Senior Government Advisor on Biotechnology
24. RV, Director, Research Institute
25. RW, Research Scientist, University

IN-DEPTH STUDY (Phase II)

Series I

Denmark (September 1996)

1. BR, Quality Control Manager, Firm A
2. CA, Chief Engineer, Firm A
3. CB, Product and Marketing Manager, Firm A
4. GJ, Logistics Manager, Firm A
5. HP, Production Manager, Firm A
6. JS, Research Secretary, Firm A
7. LS, Research Scientist, University
8. MH, Research Manager, Firm A

9. PL, Production Manager, Firm A
10. RL, Production Director, Firm A
11. SP, Engineer, Firm A
12. TJ, Maintenance Manager, Firm A

The Netherlands (October 1996)

13. AV, Professor of Food Chemistry, University
14. DW, Business Unit Manager, Firm C
15. HB, Professor of Biochemistry and Founder of DBF, University
16. HH, Research Scientist, Firm C
17. HM, Market Development Manager, Firm C
18. HS, Head of Fermentation and Down-Steam Processing, Firm C
19. JM, Director of Research, Firm D
20. MO, Head of Gene Technology, Research Institute
21. MO, Research Manager, Firm C
22. MS, Baker, Firm C
23. NM, Research Scientist, University
24. RB, Research Scientist, Firm C
25. RG, Head of Enzyme Development, Research Institute
26. RR, Head of Technical Operations, Firm D
27. RS, Professor of Biotechnology and Senior Government Advisor
28. RV, Research Secretary, University

Series II

Denmark (September 1996)

29. AW, Director, Ministry of Environment
30. BC, Programme Manager, Research, Ministry of Agriculture
31. BN, Advisor on Biotechnology, Agricultural Council
32. BR, Secretary of Committee on Science and Technology, Folketing (Parliament)
33. CB, Head of PR, Consumer Council
34. JM, Director, Biotechnology Trade Organisation
35. KM, Member of Parliament and Chairman of Scientific Committee, Folketing (Parliament)
36. KO, International Co-ordinator, Food Agency
37. LC, Director, Biotechnology Stimulation and Investment Organisation
38. LH, Programme Manager, Biotechnology, Ministry of Research
39. MO, Programme Manager, Ministry of Agriculture,
40. OT, Director, Biotechnology Information Company
41. PB, Director, Regional Investment Organisation
42. PG, Senior Advisor, Ministry of Research
43. PL, Director, National Research Foundation
44. RD, Research Manager, Business School
45. SB, Head of Research, Ministry of Agriculture and Fisheries
46. SH, Advisor on Biotechnology, Danish Dairy Board
47. TA, Programme Manager, Centre for Food Studies

The Netherlands (October 1996)

48. AH, Research Scientist, Consumer Research Institute
49. AN, Programme Manager, Biotechnology, Ministry of Agriculture
50. CB, Programme Manager, Biotechnology, Consumer Organisation
51. CR, Head of Public Relations, Consumer Organisation
52. CV, Head of Section, National Science Foundation
53. HB, Secretary, Advisory Committee on Genetic Modification, Ministry of Environment
54. HD, Policy Advisor, Ministry of Agriculture
55. KB, Consultant, Communication and Information Consultancy
56. KV, Director, Royal Academy
57. LH, Programme Manager, Biotechnology, Foundation for Public Information
58. LS, Research Manager, Office for Science and Technology
59. MH, Member of Parliament and Chairwoman of Scientific Committee, Parliament
60. MH, Programme Manager, Biotechnology, MEA
61. PL, Investment Manager, MEA
62. RW, Director-General of Science, MECS
63. WM, Programme Manager for Biotechnology, SENTER, Executive Agency of the MEA

Series III

International (November 1996 - January 1997)

64. AI, Programme Manager, Biotechnology, UNEP
65, AI, Communications Director, WIPO
66, AK, Programme Manager, Biotechnology, DGXII, CEC
67, AD, General Secretary, European Biotechnology Trade Organisation
68, BB, Research Advisor, Danish Consulate
69, BZ, Information Manager, Biotechnology, DGXII, CEC
70, CM, Programme Manager, Biotechnology and Agriculture, DGXII, CEC
71, DC, Secretary, Committee on Plant Genetics, FAO
72, EW, Advisor on Trade, Agriculture, WTO
73, GG, Secretary, UPOV
74, GS, Advisor on Trade, Agriculture, WTO
75, JP, Secretary, JEFCA, Codex
76, MC, Senior Advisor, Biotechnology, OECD
77, ML, Programme Manager, Biotechnology, DGXII, CEC
78, ML, Secretary, International Dairy Organisation
79, MS, National Expert, Biotechnology Regulation, DGIII, CEC
80, NA, Director, Danish Agricultural Council
81, NK, Danish MEP, EP
82, SC, Assistant Secretary, International Bioethics Committee, UNESCO
83, SD, Food Standards Officer, Codex
84, SH, Communications Manager, DGXII, CEC
85, SV, Trade Advisor, Biotechnology and the Environment, WTO
86, VT, Lobbyist, European Consumer Organisation

Series IV

UK (March 1997 - June 1997)

87, BC, Director, Firm A
88, BL, Technical Director, Cheese Manufacturer
89, BP, Sales Director, Firm C
90, CL, Committee Secretary, Food Advisory Committee, MAFF
91, DG, Technical Executive, Food Retailer
92, GB, Biotechnology Manager, Food Retailer
93, IF, Technical Manager, Food Retailer
94, JS, Secretary, Biotechnology Trade Organisation
95, JH, Secretary, Food Trade Organisation
96, KB, Programme Manager, Biotechnology, Management Consultancy
97, LR, Programme Manager, Biotechnology, Food Trade Organisation
98, PK, Director, Biotechnology Venture Capital Company
99, PM, Director, Innovation Unit, DTI
100, TW, Technical Director, Bread Improver Company

BIBLIOGRAPHY

ACNFP (1990) Advisory Committee on Novel Foods and Processes, *Annual Report 1989*, London: Ministry of Health and Ministry of Agriculture, Fisheries & Food.

ACNFP (1991) Advisory Committee on Novel Foods and Processes, *Annual Report 1990*, London: Ministry of Health and Ministry of Agriculture, Fisheries & Food.

Adam, B. (1996) 'Re-vision: the centrality of time for an ecological social science perspective', in S. Lash, B. Szerszynski, B. Wynne (eds) *Risk, Environment & Modernity*, London: Sage.

Afuah, A. (1998) *Innovation Management*, New York: Oxford University Press.

Aglietta, M. (1979) *A Theory of Capitalist Regulation*, London: New Left Books.

Ahern, R. (1993) 'The role of strategic alliances in the international organization of industry', in *Environment and Planning A*, 25:1229-46.

Ahmed, I. (ed.) (1992) *Biotechnology: A Hope or a Threat?*, Basingstoke: Macmillan Press.

Ahmed, I. (1995) 'The employment impact of biotechnology', in M. Fransman, G. Junne and A. Roobeek (eds) *The Biotechnology Revolution*, Oxford: Blackwell.

Ahson, K. (1994) *Can Strategic Trade Theory be Applied to Agriculture?*, unpublished MA thesis, University of Amsterdam.

Ahson, K. (1996a) 'New organisational geographies in the agro-food system: the case of novel food production', paper presented at *Geographies of Food* session at the Institute of British Geographers annual conference, Strathclyde, 4-6 January.

Ahson, K. (1996b) 'Oncomouse™ or Semacylase™?: Notes for the researcher', in P. Shurmer-Smith (ed.) *All Over the Place*, Proceedings of Postgraduate Conference in Social and Cultural Geography, University College London, June 1996.

Ahson, K. (1997) 'What is actually happening in agro-food biotechnology?', in *British Food Journal*, 99(7):263-7.

Ahson, K. (1998) 'What is biotechnology?', paper presented at *Graduate Seminar Series*, at the Department of Geography, University College London, 19 March 1998.

Albrow, M. (1996) *The Global Age*, Cambridge: Polity Press.

Alderman, N. (1998) 'Industrial innovation diffusion: the extent of use and disuse of process technologies in engineering', in *Area*, 30(2):107-16.

Aldridge, S. (1997) 'Growth Industry', in *New Scientist:Inside Science*, 105.

AMFEP (1990) *Regulatory Aspects of Microbial Food Enzymes*, Brussels: Association of Microbial Food Enzyme Producers.

AMFEP (1995a) *Enzymes, Genetic Modification and Harmonised Regulation in the EU*, Brussels: Association of Microbial Food Enzyme Producers.

AMFEP (1995b) *Historical Application of Enzymes*, Brussels: Association of Microbial Food Enzyme Producers.

AMFEP (1995c) *GMO Food Enzymes*, Brussels: Association of Microbial Food Enzyme Producers.

Amin, A. (1994) 'Post-fordism: models, fantasies and phantoms of transition', in A. Amin (ed.) *Post-Fordism: A Reader*, Oxford: Blackwell.

Amin, A and Thrift, N. (1997) 'Globalization, socio-economics, territoriality', in R. Lee and J. Wills (eds) *Geographies of Economies*, London: Arnold.

Amirahmadi, H. and Wallace, C. (1995) 'Information technology, the organization of production, and regional development', in *Environment and Planning A*, 27:1745-75.
Andersen, W. (1991) 'The past and future of agricultural biotechnology', in *Agricultural Biotechnology at the Cross-Roads*, National Agricultural Biotechnology Council Report 3, New York: NABC.
Angold, R., Beech, G. and Taggart, J. (1989) *Food Biotechnology*, Cambridge: Cambridge University Press.
Arce, A. and Marsden, T. (1993) 'The social construction of international food: a new research agenda', in *Economic Geography*, 69(3):293-311.
Aronowitz, S., Martinsons, B. and Menser, M. (eds) (1996) *technoscience and cyber culture*, New York: Routledge.
Arthur Andersen (1994) *UK biotech '94 - the way ahead*, a strategic review in conjunction with the BioIndustry Association, London: Arthur Andersen.
Arthur Andersen (1997) *UK biotech '97 - making the right moves*, London: Arthur Andersen.
Bains, W. (1997) 'Should you hire an epistemologist?', in *Nature biotechnology*, 15(5): 396.
Bajaj, J. (1988) 'Francis Bacon, the first philosopher of modern science: a non-western view', in A. Nandy (ed.) *Science, Hegemony and Violence: A Requiem for Modernity*, New Delhi: Oxford University Press.
Baker, B. (1995) 'In the beginning there was a tomato', in *Science & Public Affairs*, Summer:20-3.
Balmer, B. (1996) 'Managing mapping in the Human Genome Project', *in Social Studies of Science*, 26:531-73.
Balogh, B. (1991) *Chain Reaction*, Cambridge: Cambridge University Press.
Barley, S. (1990) 'The alignment of technology and structure through roles and networks', in *Administration Science Quarterly*, 35:61-103.
Barnes, T. (1998) 'A history of regression: actors, networks, machines and numbers', in *Environment and Planning A*, 30:203-23.
Bauman, Z. (1991) *Modernity and Ambivalence*, Oxford: Polity Press.
Beck, C. and Ulrich, T. (1993) 'Biotechnology in the food industry: an invisible revolution is taking place', in *BIO/TECHNOLOGY*, 11(8):895.
Beck, U. (1992) *Risk Society: Towards a New Modernity*, London: Sage.
Beck, U., Giddens, A. and Lash, S (1994) *Reflexive Modernization: Politics, Tradition and Aesthetics in the Modern Social Order*, Cambridge: Polity Press.
Beck-Gernsheim, E. (1996) 'Risk and the self: encounters and responses', in S. Lash, B. Szerszynski and B. Wynne (eds) *Risk, Environment & Modernity*, Sage: London.
Bennett, D. (1998) 'Cloning ban troubles Dutch', in *Chemistry & Industry*, 10:380-2.
Benton, T. and Redclift, M. (1994) 'Introduction', in M. Redclift and T. Benton (eds) *Social Theory and the Global Environment*, London: Routledge.
Bergson, H. (1954) *Creative Evolution*, London: Methuen.
Berland, J. and Kember, S. (1996) 'Editorial', in *New Formations*, October 1996:v-vii.
Berman, M. (1983) *All That is Solid Melts into Air: The Experience of Modernity* (2nd edition, first published in 1982), London: Verso.
Bernstein, W. (1995) 'Designing biosafe laboratories', in *BIO/TECHNOLOGY*, 13(10):1068-70.
Betz, F. (1998) *Managing Technological Innovation: Competitive Advantage From Change*, New York: John Wiley & Sons.

BEUC (1996) *The Consumers' Voice in the European Union*, Brussels: Bureau Européen des Unions de Consommateurs.
Bhaskar, R. (1993) *Dialectic: The Pulse of Freedom*, London: Verso.
Bhaskar, R. (1997) *A Realist Theory of Science*, London: Verso.
Bigelis, R. (1993) 'Carbohydrases', in T. Nagodawithana and G. Reed (eds) *Enzymes in Food Processing*, San Diego: Academic Press, Inc.
Bills, D. and Kung, S. (eds) (1992) *Biotechnology and Nutrition*, Boston, Mass.: Butterworth-Heinemann.
Bijker, W., Hughes, T. and Pinch, T. (eds) (1987) *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge, Mass.: MIT Press.
Bijker, W. (1995) *Of Bicycle, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*. Cambridge, Mass.: MIT Press.
Bijman, J. (1995) 'Recombinant bovine somatotropin in Europe and the USA', in *Biotechnology and Development Monitor*, 27:2-5.
Bimber, B. (1994) 'Three faces of technological determinism', in M. Smith and L. Marx (eds) *Does Technology Drive History? The Dilemma of Technological Determinism*, Cambridge, Mass.: MIT Press.
Bloor, D. (1982) 'Polyhedra and the abominations of Leviticus: cognitive styles in mathematics', in M. Douglas (ed.) *Essays in the Sociology of Perception.* London: Routledge.
Blumenthal, D., Causino, N., Campbell, E. and Louis, K. (1996) 'Relationships between academic institutions and industry in the life sciences - an industry survey, in *New England Journal of Medicine*, 334:368-73.
BMA (1986) *Diet, Nutrition and Health*, report by the Board of Science and Technology of the British Medical Association (BMA), London: BMA.
Bongert, E. (1996) 'Stimulation programmes in the European Union', in *Biotechnology and Development Monitor*, 26:6-7.
Bottomore, T. (ed.) (1991) *A Dictionary of Marxist Thought*, (2nd edition, first published in 1987), Cambridge, Mass.: Blackwell.
Bowyer, J. and Christensen, C. (1995) 'Disruptive technologies: catching the wave', in *Harvard Business Review*, January-February 1995:43-53.
Braverman, H. (1974) *Labor and Monopoly Capital*, New York: Monthly Review Press.
Breaker, R. (1997) 'DNA enzymes', in *Nature biotechnology*, 15(5):427-31.
Bridge, G. (1992) 'Questionnaire surveys', in A. Rodgers (ed.) *The Student's Companion to Geography*, Oxford: Blackwell.
Bronowski, J. (1977) 'Isaac Newton's Model', in J. Hatton and P Plouffe (eds) (1993) *The Culture of Science*, New York: MacMillan.
Bryman, A. (ed.) (1988) *Doing Research in Organizations*, London: Routledge.
Bryman, A. and Cramer, D. (1992) *Quantitative Analysis for Social Scientists*, London: Routledge.
Buchanan, R. (1992) *The Power of the Machine: The Impact of Technology from 1700 to the Present*, London: Penguin.
Buckwell, A. and Moxey, A. (1990) 'Biotechnology and agriculture', in *Food Policy*, February 1990:44-66.
Bud, R. (1993) *The Uses of Life: A History of Biotechnology*, Cambridge: Cambridge University Press.
Burke, J. and Thomas, S. (1997) 'Agriculture is biotechnology's future in Europe', in *Nature biotechnology*, 15(8):695.
Burns, T. and Stalker, G. (1994) *The Management of Innovation*, Oxford: Oxford University Press.

Buttel, F. and Goodman, D. (1989) 'Class, state, technology and international regimes', in *Sociologia Ruralis*, XXIX(2):86-91.
Buttel, F. (1995) 'Biotechnology: an epoch-making technology?', in M. Fransman, G. Junne and A. Roobeek (eds) *The Biotechnology Revolution*, Oxford: Blackwell.
Buttel, F. (1998) 'Nature's place in the technological transformation of agriculture: some reflections on the recombinant BST controversy in the USA', in *Environment and Planning A*, 30:1151-63.
BVCA (1997) *Directory of the UK Venture Capital Industry*, London: British Venture Capital Association.
Byé, P. and Fonte, M. (1994) 'Is the technical model of agriculture changing radically?', in P. McMichael (ed.) *The Global Restructuring of Agro-Food Systems*, Itacha: Cornell University Press.
Byman, J. (1990) 'New technologies in the agro-food system and US-EC trade relations', in P. Lowe, T. Marsden and S. Whatmore (eds) *Technological Change and the Rural Environment*, London: David Fulton Publishers.
Caffentzis, C. (1997) 'Why machines cannot create value; or, Marx's theory of machines', in J. Davis, T. Hirschl and M. Stack (eds) *Cutting Edge*, London: Verso.
Callan, B. (1996) *Why Productive Technology is not a Measure of Competitiveness in the Biotechnologies*, internet document, http/brie.berkeley.edu/BRIE/pubs/wp/wp86.mtm.
Callon, M. (1986a) 'Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc bay', in J. Law (ed.) *Power, Action and Belief: A New Sociology of Knowledge?*, London: Routledge.
Callon, M. (1986b) 'The sociology of an actor network', in M. Callon, J. Law and A. Rip (eds) *Mapping the Dynamics of Science and Technology*, London: Macmillan.
Callon, M. (1992) 'The dynamics of techno-economic networks', in R. Coombs, P. Saviotti and V. Walsh (eds) *Technological Change and Company Strategies: Economic and Sociological perspectives*, London: Harcourt Brace Jovanovich.
Callon, M. (1997) 'Actor-Network Theory - The Market Test', paper presented at the *Actor Network and After* workshop, July 1997, internet document, http:/www.keele.ac./depts/stt/cstt2/ant/callon.htm.
Cantley, M. (1995) *The Regulation of Modern Biotechnology: A Historical and European Perspective*, Weinham: VCH.
Cantor, C. (1998) 'How will the Human Genome Project improve our quality of life?', in *Nature biotechnology*, 16(3):212-3.
Carchedi, G. (1997) 'High-tech hype: promises and realities of technology in the twenty first century', in J. Davis, T. Hirschl and M. Stack (eds) *Cutting Edge*, London: Verso.
Cardwell, D. (1994) *The Fontana History of Technology*, London: Fontana Press.
Carroll, G. and Teo, C. (1996) 'On the social networks of managers', in *Academy of Management Journal*, 39(2):421-40.
Carson, R. (1965) *Silent Spring*, London: Penguin.
Caspari, C. and Neville-Rolfe, E. (1989) 'The impact of biotechnology', in *The Future of European Agriculture: Trade, Technology and the Environment*, London: The Economist Intelligence Unit.
Castells, M. (1996) *The Rise of the Network Society*, Oxford: Blackwell.
CC (1996) *Greater Copenhagen has much to offer the Biotechnology Industry*, Copenhagen: Copenhagen Capacity (CC).

CEC (1989) *The Impact of Biotechnology on Agriculture in the European Community to the year 2005: Study Prepared for Directorate General for Agriculture*, Luxembourg: Commission of the European Communities.
CEC (1993) *Growth, Competitiveness and Employment: The Challenges and Ways Forward for the 21st Century*, Luxembourg: Commission of the European Communities.
CEC (1994) *Community Research and Technological Development Policy*, Luxembourg: Commission of the European Communities (DG XII).
CEC (1996a) *Green Paper on Innovation*, Luxembourg: Commission of the European Communities.
CEC (1996b) *Inventer Demain*, Luxembourg: Commission of the European Communities (DG XII).
CEC (1997a) *Les Européens et la Biotechnologie Moderne. Eurobarometre, 46.1*, Luxembourg: Commission of the European Communities (DG XII).
CEC (1997b) *Commission Green Paper: The General Principles of Food Law in the European Union*, Luxembourg: Commission of the European Communities.
CEC (1998a) *RTD info. Research, Employment, Youth: A New Alliance*, 17, Luxembourg: Commission of the European Communities.
CEC (1998b) 'Investors and Biotechnologists do business', in *Innovation & Technology Transfer*, 4/98:4.
CEC (1998c) 'Breakthrough on fifth RTD framework programme', in *Cordis focus*, 23 February 1998:1.
CEC (1998d) 'Biotechnology: is the tide turning in Europe's favour?', in *Innovation & Technology Transfer*, 3/98:16-21.
Chalmers, A. (1988) *What is This Thing Called Science?* (2nd edition, first published in 1982), Milton Keynes: Open University Press.
Coghlan, A. (1997) 'Better out than in', in *New Scientist*, 2103:7.
Cohen, P. (1998) 'Crossing the line', in *New Scientist*, 2117:4-5.
Cohen, R. and Wartofsky, M. (eds) (1983) *Epistemology, Methodology, and the Social Sciences*, Dordrecht: D. Reidel Publishing Company.
Collins, H. and Yearley, S. (1992) 'Epistemological chicken', in A. Pickering (ed.) *Science as Practice and Culture*, Chicago: Chicago University Press.
Cook, I. and Crang, M. (1995) *Doing Ethnographies*, London: CATMOGS.
Cook, I. and Crang, P. (1996) 'The world on a plate', in *Journal of Material Culture*, 1(2):131-53.
Cooke, P. and Morgan, P. (1993) 'The network paradigm: new departures in corporate regional development', in *Environment and Planning D*, 11:543-64.
Coombs, J. and Alston, Y. (1995) *The International Biotechnology Directory*, London: Macmillan.
Coombs, R., Saviotti, P. and Walsh, V. (1987) *Economics and Technological Change*, London: Macmillan.
Coombs, R., Saviotti, P. and Walsh, V. (1992) 'Technology and the firm: the convergence of economic and sociological approaches?', in R. Coombs, P. Saviotti and V. Walsh (eds) *Technological Change and Company Strategies: Economic and Sociological Perspectives*, London: Harcourt Brace Jovanovich.
Cooper, D. (1996) *Thinkers of our Time: Heidegger*, London: The Claridge Press.
Cowan, D. (1996) 'Industrial enzyme technology', in *Trends in Biotechnology*, 14:177-8.
Cox, K. (1998) 'Spaces of dependence, spaces of engagement and the politics of scale, or looking for local politics', in *Political Geography*, 17:1-23.

Crang, M., Hudson, A., Reamer, S. and Hinchliffe, S. (1997) 'Software for qualitative research: 1. Prospects and overview', in *Environment and Planning A*, 29:771-87.

Crespi, R. (1995) 'The European biotechnology patent directive is dead', in *Trends in Biotechnology*, 13:162-164.

Crewe, L. (1996) 'Material culture: embedded firms, organizational networks and the local economic development of a fashion quarter', in *Regional Studies*, 30(3):257-72.

Cross, H. (1992) 'Food safety perspectives on animal biotechnology', in J, MacDonald (ed.) *Animal Biotechnology Technology: Opportunities & Challenges*, National Agricultural Biotechnology Council Report 4, Ithaca, New York: NABC.

Cussins, C. (1998) 'Ontological choreography: agency for women patients in an infertility clinic', in A. Mol and M. Berg (eds) *Differences in Medicine: Unravelling Practices, Techniques and Bodies*, Durham, North Carolina: Duke University Press.

Darrington, H. (1995) 'Focus on functional foods', in *Food Manufacture*, April 1995: 25-8.

DaSilva, E., Ratledge, C. and Sasson, A. (eds) (1992) *Biotechnology: Economic and Social Aspects: Issues for Developing Countries*, Cambridge: Cambridge University Press.

Davidson, S. (1997) 'Why venture capital will fund industrial biotechnologies soon', in *Nature biotechnology supplement*, June 1997:20.

Davies, G. (1997) *Networks of Nature: Stories of Natural History Film-Making from the BBC*, unpublished PhD thesis, University of London.

Davis, B. (ed.) (1991) *The Genetic Revolution: Scientific Prospects and Public Perceptions*, Baltimore: John Hopkins University Press.

Davis, J., Hirschl, T. and Stack, M. (1997) 'Introduction', in J. Davis, T. Hirschl and M. Stack (eds) *Cutting Edge*, London: Verso.

Dekker, R. (1994) 'Enzymes in food and beverage processing (1)', in *Food Australia*, 46(3):136-9.

Demirag, I. (1996) 'From common sense to short-termism: reflections on R&D managers' perceptions', in A. Belcher, J. Hassard and S. Procter (eds) *R&D Decisions: Strategy, Policy and Innovations*, London: Routledge.

Derry, T. and Williams, T. (1970) *A Short History of Technology*, Oxford: Oxford University Press.

Deshayes, A. (1994) 'Environmental and social impacts of GMOs: what have we learned from the past few years', Keynote address at the 3rd International Symposium on *The Biosafety Results of Field Tests of Genetically Modified Plants and Micro-organisms*, Monterey, California, 13-16 November 1994.

Diamond, J. (1998) *Guns, Germs and Steel*, London: Vintage.

Dicken, P. and Thrift, N. (1992) 'The organization of production and the production of organization: why business enterprises matter in the study of geographical industrialization', in *Transactions of the British Geographers*, 17:279-91.

Dickens, P. (1996) *Reconstructing Nature: Alienation, Emancipation and the Division of Labour*, London: Routledge.

Dixon, B. (1995) 'Public understanding doesn't always lead to public support', in *BIO/TECHNOLOGY*, 13(6):532.

DNRF (1994) *The Danish National Research Foundation*, Copenhagen: DNRF.

Dodgson, M. (1991) 'Technology learning, technology strategy and competitive pressures', in *British Journal of Management*, 2:133-49.
Dodgson, M. (1992) 'Strategy and technological learning: an interdisciplinary microstudy', in R. Coombs, P. Saviotti and V. Walsh (eds) *Technological Change and Company Strategies*, London: Harcourt Brace Jovanovich.
Dörnenburg, H. and Lang-Hinrichs, C. (1994) 'Genetic engineering in food biotechnology', in *Chemistry & Industry*, 13:506-10.
Dosi, G. (1982) 'Technological paradigms and technological trajectories', in *Research Policy*, 11(3):147-62.
Dosi, G. (1988) 'Sources, procedures, and microeconomic effects of innovation', in *Journal of Economic Literature*, XXVI, 1120-71.
DRC (1993) *Danish Research Council Committee on Biotechnology: Midterm Evaluation of the Danish Biotechnological Research and Development Programme 1991-1995*, Copenhagen: Danish Research Council (DRC).
Dreyfus, H. and Hall, H. (1992) 'Introduction', in H. Dreyfus and H. Hall (eds) *Heidegger: A Critical Reader*, Oxford: Blackwell.
DTI (1995a) *Biotechnology Means Business. Status Report: Waste Treatment*, London: Department of Trade and Industry.
DTI (1995b) *Biotechnology Means Business. Status Report: Food*, London: Department of Trade and Industry.
DTI (1996a) *Case Studies of Biotechnology in Action*, 1, Spring 1996, London: Department of Trade and Industry.
DTI (1996b) *Case Studies of Biotechnology in Action*, 2, Winter 1996, London: Department of Trade and Industry.
DTI (1996c) 'Genetically Modified Tomato Purée for Sale', in *Biotechnology News*, London: Department of Trade and Industry.
DTI (1997) *Case Studies of Biotechnology in Action*, 3, Winter 1997, London: Department of Trade and Industry.
Ducastaing, A. and Adrian, J. (1990) 'Les enzymes en technologie alimentaire', in *Sciences des Aliments*, 10:231-254.
Durant, J. (ed.) (1992) *Biotechnology in Public*, London: Science Museum.
Durant, J. (1996) 'The challenge of modern biotechnology', keynote paper presented at the *National Review Conference on Food and Modern Biotechnology*, 18 March 1996, London: The Food and Drink Federation.
Duysters, G. and Hagedoorn, J. (1995) 'Strategic groups and inter-firm networks in international high-tech industries', in *Journal of Management Studies*, 32(3): 359-81.
Economidis, I. (1994) *An Overview of the Biotechnology Research Activities in the European Community*, Brussels: Commission of the European Communities (DGXII).
Economist (1988) ' The genetic alternative', special report, 30 April 1988.
Economist (1995) 'Biotechnology and genetics', special report, 25 February 1995.
Economist (1996a) 'The long and the short of designer fats', 7 September 1996:96.
Economist (1996b) 'A moral maize', 14 September 1996:114.
Economist (1996c) 'The human genome', 14 September 1996:19-20.
Economist (1997a) 'Genetically engineered food: of greens and american beans', 4 January 1997:62.
Economist (1997b) 'Hello Dolly', 1 March 1997:17.
Economist (1998) 'In defense of the demon seed', 13 June 1998:13-4.

Eden, S. (1996) 'Public participation in environmental policy: considering scientific, counter-scientific and non-scientific contributions', in *Public Understanding of Science*, 5:183-204.
Edgington, S. (1997) 'Did George do the right thing?', in *Nature biotechnology*, 14(8): 926.
EFB (1994) *Briefing paper No. 2:Biotechnology in Foods and Drinks*, Brussels: European Federation of Biotechnology.
EFB (1995) *European Federation of Biotechnology Newsletter*, July 1995, London: Macmillan Press.
Eley, A. (1997) 'Escherichia coli 0157: an increasingly significant food poisoning pathogen', in *Nutrition & Food Science*, May/June:96-100.
Elliot, B. (1988) 'Introduction', in B. Elliot (ed.) *Technology and Social Process*, Edinburgh: Edinburgh University Press.
Elliot, J. (1980) 'Marx and Schumpeter on capitalism's creative destruction: a comparative restatement', in C. Freeman (ed.) (1990) *The Economics of Innovation*, Aldershot: Edward Elgar.
Ellul, J. (1965) *The Technological Society*, London: Jonathan Cape.
Emery, F. and Trist, L. (1960) 'Socio-technical systems', in C. Churchman and E. Verhulst (eds) *Management Science, Models and Techniques*, London: Pergamon Press.
EP (1994) *Regulation and Competitiveness of the European Biotechnology Industry*, Luxembourg: European Parliament.
Ernst & Young (1994) *Biotechnology's Economic Impact in Europe: A Survey of its Future Role in Competitiveness*, London: Ernst & Young.
Ernst & Young (1996) *European Biotech 96: Volatility and Value*, London: Ernst & Young.
Ernst & Young (1998) *European Life Sciences 98:Continental Shift*, London: Ernst & Young.
Europabio (1996) *Bionews*, August 1996, Brussels: Europabio.
Europabio (1997) *Benchmarking the Competitiveness of Biotechnology in Europe*, an independent report for Europabio by Business Decisions Limited and the Science Policy Research Unit, Brussels: Europabio.
Eyles, J. (ed.) (1988) *Research in Human Geography: Introductions and Investigations*, Oxford: Basil Blackwell.
FAC (1992) *Food Advisory Committee Annual Report 1991*, London: HMSO.
FAC (1996) *Food Advisory Committee Annual Report 1995*, London: HMSO.
Fairtlough, G. (1996) 'Focusing the DTI on networks', in *Demos*, 8:49-51.
Faulkner, W. (1994) 'Conceptualizing knowledge used in innovation: a second look at the science-technology distinction and industrial innovation', in *Science, Technology & Human Values*, 19(4):425-58.
FDF (1996a) *Consumers and Biotechnology*, report on research conducted for the Food and Drink Federation, London: Food and Drink Federation.
FDF (1996b) *Food For Our Future: Food and Biotechnology*, London: Food and Drink Federation.
FDF (1996c) *Food For Our Future: A Guide to Modern Biotechnology*, London: Food and Drink Federation.
FDF (1998) *Foodfuture*, information pack, London: Food and Drink Federation.
Feenberg, A. (1995) *Alternative Modernity: The Technical Turn in Philosophy and Social Theory*, Berkeley, Ca.: University of California Press.

Fell, J. (1992) 'The familiar and the strange: the limits of praxis in the early Heidegger', in H. Dreyfus and H. Hall (eds) *Heidegger: A Critical Reader*, Oxford: Blackwell.
Feyerabend, P. (1993) *Against Method* (3rd edition, first published in 1975), London: Verso.
Financial Times (1995) 'Biotechnology Survey: billions spent on global quest for wonder cures', 27 November 1995: I-IV.
Financial Times (1997a) 'British Biotech set for first drug launch', 13 May 1997:24.
Financial Times (1997b) 'Blow for biotech industry', 22 May 1997:1.
Financial Times (1997c) 'ICI pays £4.9bn for Unilever arm', 8 May 1997:1.
Finch, J. (1984) 'It's great to have someone to talk to: the ethics and politics of interviewing women', in C. Bell and H. Roberts (eds) *Social Researching: Politics, Problems and Practice*, RKP, London.
Fine, B. and Leopold, E. (1993) *The World of Consumption*, London: Routledge.
Flavell, R. (1995) 'Plant biotechnology R&D - the next ten years', in *Trends in Biotechnology*, September 1995,13:313-9.
Florida, R. (1996) 'Regional creative destruction: production organization, globalization, and the economic transformation of the Midwest', in *Economic Geography*, 72(8):314-34.
Ford, B. (1995) 'The nature of innovation', in *Biologist*, 42(5):236-8.
Forskingsirektoratet (1990) *Det Bioteknologiske Forsknings -og Udviklingsprogram 1987-1990*, Copenhagen: Forskingsirektoratet (Danish Research Council).
FØTEK (1993) *The Danish Research and Development Programme for Food Technology: Result of the International Mid-Term Evaluation*, Copenhagen: Committee on Food Technology, The Danish Research Council.
FØTEK (1995). *Koordineringsgruppens Afslutningsrapport til Ministergruppen. Koordineringsgruppen* (The Danish Research and Development Programme for Food Technology), Copenhagen: The Danish Research Council.
Fox, J. (1997a) 'Europe and FDA agree to limited inspections', in *Nature biotechnology*, 15(8):714-5.
Fox, J. (1997b) 'Biotech food labelling: polite hedging or loggerheads?' in *Nature biotechnology*, 15(4):308.
Fox, J. (1998) 'US to EU: please, pass the maize', in *Nature biotechnology*, 16(1):11.
Fransman, M., Junne, G. and Roobeek, A. (eds) (1995) *The Biotechnology Revolution*, Oxford: Blackwell.
Fransman, M. and Tanaka, S. (1995) 'The strengths and weaknesses of the Japanese innovation system in biotechnology', in M. Fransman, G. Junne and A. Roobeek (eds) (1995) *The Biotechnology Revolution*, Oxford: Blackwell.
Freeman, C. (1988) 'Introduction', in G. Dosi, C. Freemen, R. Nelson, G. Silverberg and L. Soete (eds) *Technical Change and Economic Theory*, London: Pinter Publishers.
Freeman, C. and Perez, C. (1988) 'Structural crises of adjustment: business cycles and investment behaviour', in G. Dosi, C. Freemen, R. Nelson, G. Silverberg and L. Soete (eds) *Technical Change and Economic Theory*, London: Pinter Publishers.
Freeman, C. (1990) 'Introduction', in C. Freeman (ed.) *The Economics of Innovation*, Aldershot: Edward Elgar.
Freeman, C. (1991) 'Technical innovation in the world chemical industry and changes of techno-economic paradigm', in C. Freeman and L. Soete (eds) *New Explorations in the Economics of Technical Change*, London: Pinter.

Friedland, R. and Boden, D. (1994) 'NowHere: an introduction', in R. Friedland and D. Boden (eds) *NowHere: Space, Time and Modernity*, Berkeley, Ca.: University of California Press.
Frisby, D. (1986) *Fragments of Modernity: Theories of Modernity in the Work of Simmel, Kracauer, and Benjamin*, Cambridge, Mass: MIT Press.
Gamble, A. (1996) 'Embedded statism', in *Environment and Planning A*, 28:1933-6.
Ganguly, A. (1995) 'Science of food in the twenty-first century', in *Nutrition & Food Science*, 2:17-20.
Gershon, D. (1997) 'Agricultural biotechnology comes of age', in *Nature biotechnology*, supplement, June 1997:9.
Gertler, M. (1995) '"Being there": proximity, organization and culture in the development and adoption of advanced manufacturing technologies', in *Economic Geography*, 71(1):1-26.
Geschwindt, S. (1997) 'Driving towards a green light', in *Nature biotechnology* supplement, June 1997:25-9.
Giddens, A. (1990) *The Consequences of Modernity*, Oxford: Polity Press.
Giddens, A. (1991) *Modernity and Self Identify: Self and Society in the Late Modern Age*, Oxford: Polity Press.
Giddens, A. (1994) 'Living in a post-traditional society', in U. Beck, A. Giddens and S. Lash (eds) *Reflexive Modernization: Politics, Tradition and Aesthetics in the Modern Social Order*, Cambridge: Polity Press.
Gist brocades (1991) *Biotechnology, Today and Tomorrow*, Delft: Gist brocades.
Glasner, V. (1997) 'Biotech unruffled by setbacks', in *Nature biotechnology*, 15(7):610-1.
Goldburg, R. and Greenlee, W. (1993) 'Technical risk assessment and regulations', in J. MacDonald (ed.) *Agricultural Biotechnology: A Public Conversation*, National Agricultural Biotechnology Council Report 5, Ithaca, New York: NABC.
Goodman, D., Sorj, B. and Wilkinson, J. (1987) *From Farming to Biotechnology: A Theory of Agro-Industrial Development*, Oxford: Basil Blackwell.
Goodman, D. and Wilkinson, J. (1990) 'Patterns of research and innovation in the modern agro-food system', in P. Lowe, T. Marsden and S. Whatmore (eds) *Technological Change and Economic Theory*, London: Fulton.
Goodman, D. and Redclift, M. (1991) *Refashioning Nature: Food, Ecology and Culture*, Routledge: London.
Goodman, D. and Watts, M. (1994) 'Reconfiguring the rural or fording the divide?: capitalist restructuring and the global agro-food system', in *The Journal of Peasant Studies*, 22(1):1-49.
Golub, E (1997) 'Genetically enhanced food for thought', in *Nature biotechnology*, 15(2):112.
Gordon, M. (1997) 'Suffering of the lambs', in *New Scientist*, 2079:16-7.
Goss, P. (1996) 'Guiding the hand that feeds: toward socially optimal approprability in agricultural biotechnology innovation', in *California Law Review*, 84(5): 1395-436.
Gower, B. (1997) *Scientific Method: An Historical and Philosophical Introduction*, London: Routledge.
Grace, E. (1997) *Biotechnology Unzipped: Promises & Realities*, Washington DC: Joseph.
Graf, E. and Saguy, I. (eds) (1991) *Food Product Development: From Concept to Marketplace*, New York: Van Nostrand Reinhold.

Grant, A. and Schlesinger, L. (1995) 'Realize your customers' full profit potential', in *Harvard Business Review*, September-October 1995:59-72.
Grasius, M., Iyengar, L. and Venkobachar, C. (1997) 'Anaerobic biotechnology for the treatment of wastewaters: a review', in *Journal of Scientific & Industrial Research*, 56(7):385-97.
Greenberg, D. (1995) 'Social irresponsibility', in *Nature*, 374:1278.
Greenwald, P. (1992) 'Impact of diet on human oncology', in D. Bills and S. Kung (eds) *Biotechnology and Nutrition*, Boston, Mass.: Butterworth-Heinemann.
Greenwood, J. and Ronit, K. (1994) 'The ABCs of biotechnology lobbying organizations in Europe', in *BIO/TECHNOLOGY*, 12:371-4.
Gregory, D. (1994) *Geographical Imaginations*, Oxford: Blackwell.
Green, K. (1992) 'Creating demand for biotechnology: shaping technologies and markets', in R. Coombs, P. Saviotti, and V. Walsh (eds) *Technological Change and Company Strategies: Economic and Sociological Perspectives*, London: Harcourt Brace Jovanovich.
Grint, K. and Woolgar, S. (1997) *The Machine at Work: Technology, Work and Organization*, Oxford: Polity Press.
Grove-White, R., Macnaghten, P., Mayer, S. and Wynne, B. (1997) *Uncertain World: Genetically Modified Organisms, Food and Public Attitudes in Britain*, report by the Centre for the Study of Environmental Change in association with Unilever, Lancaster: Lancaster University.
Guardian (1994) 'Designer genes', 24 September 1994:58-9.
Guardian (1996a) 'The trojan tomato', 16 March 1996, Section 2:44.
Guardian (1996b) Advert for Yakult, 20 April 1996:9
Guardian (1997a) ' Food: the £250bn gamble', 15 December 1997:1.
Guardian (1997b) 'Ministers' alarm at genetic food revolution', 16 December 1997:1.
Guardian (1997c) 'Backlash against genetic farming', 17 December 1997:4.
Guardian (1998a) 'Baby-cloning clinic projected', 7 January 1998:6.
Guardian (1998b) 'Cancer key gene discovery', 28 April 1998:1.
Guardian (1998c) 'Rumours leave British Biotech on the ropes', 28 April 1998:3.
Guardian (1998d) 'Sainsbury believes an insect is better than an insecticide', advert, 20 September 1998:18-9.
Guardian (1998e) 'Beware the bio-century', 28 October 1998, Section 2:4-5.
Haber, E. (1996) 'Industry and the university', in *Nature biotechnology*, 14(4):441-2.
Habermas, J. (1985) 'Modernity - an incomplete project', in P. Waugh (ed.) (1992) *Postmodernism: A Reader*, London: Edward Arnold.
Habermas, J. (1992) 'Work and weltanschauung: the Heidegger controversy from a German perspective', in H. Dreyfus and H. Hall (eds) *Heidegger: A Critical Reader*, Oxford: Blackwell.
Hacking, A. (1988) *Economic Aspects of Biotechnology*, Cambridge: Cambridge University Press.
Hagedoorn, J. (1993) 'Understanding the rationale of strategic technology partnering: interorganizational modes of co-operation and sectoral differences', in *Strategic Management Journal*, 14:371-85.
Hagedoorn, J. (1994) 'Schumpeter: an appraisal of his theory of innovation and entrepreneurship', *MERIT Research Memorandum 2/94-020*, Limburg, the Netherlands: Maastricht Economic Research Institute on Innovation and Technology.
Hagedorn, C. and AllenderHagedorn, S. (1997) 'Issues in agricultural and environmental biotechnology: identifying and comparing biotechnology

issues from public opinion surveys, the popular press and technical/regulatory sources', in *Public Understanding of Science*, 6(3):233-45.
Hall, P. (1994) *Innovation, Economics & Evolution*, New York: Harvester.
Hallman, W. (1996) 'Public perceptions of biotechnology: another look', in *BIO/TECHNOLOGY*, 14(1):35-8.
Halton, E. (1995) 'The modern error: or, the unbearable enlightenment of being', in M. Featherstone, S. Lash and R. Robertson (eds) *Global Modernities*, London: Sage.
Hamilton, N. (1998) *Attack of the Genetically Engineered Tomatoes*, Suffolk: Nemesis Press.
Hammersley, M. (1992) *What's Wrong with Ethnography?*, London: Routledge.
Hammond, J. (1994) 'Breadmaking with hemicellulase: overcoming the legal hurdles', in A. Turner (ed.) *Food Technology International - Europe*, London: Sterling Publications Group.
Hansen, M. (1991) 'Consumer concerns: give us the data', in J. MacDonald (ed.) *Agricultural Biotechnology at the Cross-Roads*, Ithaca, NY: National Agricultural Biotechnology Council.
Haraway, D. (1992) 'When man™ is on the menu', in J. Crary and S. Kwinter (eds) *Incorporataions*, Zone: New York.
Haraway, D. (1997) *Modest_Witness@Second_Millenium. Femaleman©_Meets_OncoMouse ™*, New York: Routledge.
Harvey, D. (1982) *The Limits to Capital*, Oxford: Basil Blackwell.
Harvey, D. (1989) *The Condition of Postmodernity*, Oxford: Basil Blackwell.
Harvey, D. (1996) *Justice, Nature & the Geography of Difference*, Oxford: Basil Blackwell.
Hasler, C. (1998) 'A new look at an ancient concept', in *Chemistry & Industry*, 2 February 1998, 2:84-9.
Hatch, D. (1996) 'Building a bridge of understanding', in B. Marshall and F. Miller (eds) *Biotechnologies in Agriculture and Food - Coming to the Market*, Reading: Centre for Agricultural Studies.
Haug, P. (1995) 'Formation of biotechnology firms in the Greater Seattle region: an empirical investigation of entrepreneurial, financial, and educational perspectives', in *Environment and Planning A*, 27:249-67.
Hauschildt, J. (1993) *Innovations Management*, Munich: Vahlen.
Hayenga, M. (1993) 'Food and agricultural biotechnology: economic implications', in *American Journal of Clinical Nutrition*, supplement, 53:313-6.
Healey, M. and Ilbery, B. (1992) *Location & Change: Perspectives on Economic Geography*, Oxford: Oxford University Press.
Heidegger, M. (1966) *Discourse on Thinking*, New York: Harper & Row.
Heidegger, M. (1977) *The Question Concerning Technology and Other Essays*, New York: Harper & Row.
Heidegger, M. (1995) *Being and Time*, Oxford: Blackwell.
Herod, A. (1997) 'From a geography of labor to a labor geography: labor's spatial fix and the geography of capitalism', in *Antipode*, 29(1):1-31.
Hew, C. and Fletcher, G. (1997) 'Transgenic fish for aquaculture', in *Chemistry & Industry*, 21 April 1997, 18:311-5
Hewitt, L. (1994) 'An attractive alternative', in *Food Manufacture*, May 1994:25-6.
Hilpert, U. (ed.) (1991) *Regional Innovation and Decentralization*, London: Routledge.
Hinchliffe, S. (1996) 'Technology, power, and space - the means and ends of geographies of technology', in *Environment and Planning D: Society and Space*, 14:659-82.

Hinchliffe, S., Crang, M., Reamer, S. and Hudson, A. (1997) 'Software for qualitative research: 2. Some thoughts on 'aiding' analysis, in *Environment and Planning A*, 29:1109-24.
Hindess, B. (1986) 'Interests in political analysis', in J. Law (ed.) *Power, Action and Belief*, London: Routledge.
Hippel von, E. (1988) *The Sources of Innovation*, Oxford: Oxford University Press.
Hodgson, J. (1994) 'The changing bulk biocatalyst market', in *BIO/TECHNOLOGY*, 12:789-90.
Hodgson, J. (1997a) 'The promises mature', in *Nature biotechnology*, supplement, June 1997:3-5.
Hodgson, J (1997b) 'Dolly opens a farm full of possibilities', in *Nature biotechnology*, 15(4):306.
Hodgson, J. (1997c) 'Euro indecision triggers food anarchy', in *Nature biotechnology*, 15(13):1331.
Hodgson, J. (1998) 'Maize faces new hurdle in EU', in *Nature biotechnology*, 16(1):11.
Hollingsworth, P. (1995) 'Food research: co-operation is the key', in *Food Technology*, February 1995:67-74.
Howells, J. (1994) *Managers and Innovation: Strategies for a Biotechnology*, London: Routledge.
Hughes, T. (1983) *Networks of Power, Electrification in Western Society 1880-1930*, Baltimore: John Hopkins University Press.
Hughes, T. (1987) 'The evolution of large technological systems', in W. Bijker, T. Hughes and T. Pinch (eds) *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge, Mass.: MIT Press.
Humphrey, A. (1996) 'Some issues in biotechnology commercialization', in *Technology in Society*, 18(3):321-32.
Iansiti, M. (1995) 'Shooting the rapids: managing product development in turbulent environments', in *California Management Review*, 38(1):37-59.
Iceland (1998) *Genetic Modification of Food and How it Affects You*, in-store leaflet for Iceland Frozen Foods Plc, Deeside: Iceland Frozen Foods Plc.
IDF (1996) *Programme of Work, 1996*, Brussels: International Dairy Federation (IDF).
IFST (1998) 'Genetic modification and food', *Institute of Food Science & Technology Hot Topic 10*, internet document, http://www.easynet.co.uk/ifst/hottop10.htm.
IGD (1997) *Communicating and Labelling Guidelines for Genetically Modified Foods*, Watford: Institute of Grocery Distribution.
Ihde, D. (1979) *Technics and Praxis*, London: D. Reidel Publishing Company.
Ihde, D. (1993) *Philosophy of Technology: An Introduction*, New York: Paragon House.
Ihde, D. (1995) *Postphenomenology: Essays in the Postmodern Context*, Evanston, Illinois: Northwestern Univerity Press.
IMD (1996) *The World Competitive Year Book*, Lausanne: IMD.
Ingrassia, A. (1996) 'Trade Related Environmental Measures in the field of safety in Biotechnology', paper presented at the workshop on *Transboundary Movement of Living Modified Organisms Resulting from Modern Biotechnology: issues and opportunities for policy makers*, 19-20 July 1996 Aarhus, Denmark.
Inkpen, A. (1996) 'Creating knowledge through collaboration', in *California Management Review*, 39(1):123-40.
Independent (1995) 'MEPs reject gene patenting', 2 March 1995:3.
Independent (1996a) 'Genetically altered maize has already arrived in Britain', 9 December 1996:7.

Independent (1996b) 'Nothing to fear from techno-corn', 11 December 1996:15.
Independent (1997) 'Crop trade wars and the maize of confusion', 16 May 1997:21.
Independent (1998a) 'Human cloning pioneer dismisses ethical doubts', 8 January 1998:3.
Independent (1998b) 'Foul food: can the Government protect us from killer bugs', 15 January 1998:3.
Independent (1998c) 'Food chain bans genetic foods', 16 March 1998:5.
Independent (1998d) 'GM food stunts rats' growth', 10 August 1998:6.
Jacob, M. (1993) *The Cultural Meaning of the Scientific Revolution*, New York: McGraw-Hill.
Jewkes, J., Sawers, D. and Stillerman, R. (1969) *The Sources of Invention*, London: Macmillan.
Johnson E (1997a) 'European politicians pass food regulations lacking meat', in *Nature biotechnology*, 15(2):210.
Johnson, E. (1997b) 'A benchside guide to patents and patenting', in *Nature biotechnology*, 14(3):288-91.
Johnston, R. (1980) 'On the nature of explanation in human geography', in *Transactions of the Institute of British Geographers*, 5(4):402-12.
Johnston, R., Gregory, D. and Smith, D. (eds) (1990) *The Dictionary of Human Geography*, Oxford: Blackwell.
Jones, D. and Cordle, M. (1995) 'Prospects for the genetic manipulation of dairy cattle: opportunities beyond BST', in *Biotechnology Advances*, 3(2):235-46.
Jones, K. (1993) 'Classifying biotechnologies', in G. Persley (ed.) *Agricultural Biotechnology: Opportunities for International Development*, London: Flamingo.
Jones, S. (1996) *In the Blood: God, Genes and Destiny*, London: Harper Collins.
Jordan, E. and Tricker, B. (1995) 'Information strategy: alignment with organization structure', in *Journal of Strategic Information Systems*, 4(4):357-82.
Jorritsman, R. (1993) 'Intellectual property', in R. van der Kwaak and G. Hersbach (eds) *Biotech Opportunities in Europe: Establishing and Operating a Health Care Biotech Venture*, Amsterdam: Eurotech Capital.
Junne, G. (1990) 'The impact of biotechnology on international commodity trade', paper presented at the *International Seminar on the Economic and Sociocultural Implications of Biotechnologies*, Verzeley, France, 29-31 October, 1990.
Junne, G. (1995) 'The impact of biotechnology on international trade', in M. Fransman, G. Junne and A. Roobeek (eds) *The Biotechnology Revolution*, Oxford: Blackwell.
Kaplinsky, R. (1984) *Automation: The Technology and Society*, Harlow: Longman.
Kareiva, P. and Stark, J. (1994) 'Environmental risks in agricultural biotechnology', in *Chemistry & Industry*, 2:52-5
Katchalski-Katzir, E. (1993) 'Immobilized enzymes - learning from past successes and failures', in *Trends in Biotechnology*, 114:471-8.
Katz, F. (1996) 'Biotechnology - new tools in food technology's toolbox', in *Food Technology*, November 1996:63-5.
Kaye, H. (1986) *The Social Meaning of Modern Biology*, New Haven: Yale University Press.
Kealey, T. (1996) *The Economic Laws of Scientific Research*, London: MacMillan Press.
Keller, E. (1992) *Secrets of Life, Secrets of Death: Essays on Language, Gender and Science*, New York: Routledge.

Kelly, P., Krantzberg, M., Rossini, F., Baker, N., Tarpley, F. and Mitzner, M. (1989) 'Introducing innovation', in R. Roy and D. Wield (eds) *Product Design and Technological Innovation*, Milton Keynes: Open University Press.
Kendall, A., McDonald, A. and Williams, A. (1997) 'The power of biomass', in *Chemistry & Industry*, 5 May, 1997, 9:342-5.
Kenney, M. and Florida, R. (1993) *Beyond Mass Production: The Japanese System and its Transfer to the US*, New York: Oxford University Press.
Kenney, M. (1995) 'University-industry relations in biotechnology', in M. Fransman, G. Junne and A. Roobeek (eds) *The Biotechnology Revolution*, Oxford: Blackwell.
Kenney, M. (1997) 'Value creation in the late twentieth century: the rise of the knowledge worker', in J. Davis, T. Hirschl and M. Stack (eds.) *Cutting Edge*, London: Verso.
Kerr, A., Cunningham-Burley, S. and Amos, A. (1998) 'Eugenics and the new genetics in Britain: examining contemporary professionals' account', in *Science, Technology & Human Values*, 23(2):175-98.
Kevles, D. (1994). 'Ananda Ckakrabarty wins a patent: biotechnology, law and society, 1972-1980', in *Historical Studies in the Physical and Biological Sciences*, 25(1):111-35.
Kevles, D. (1997) 'Big science and big politics in the United States: reflections on the death of the SSC and the life of the Human Genome Project', in *HSPS*, 27(2): 269-97.
Kherrati, B., Faid, M., Elyachioui, M. and Wahmane, A. (1998) 'Process for recycling slaughterhouses waste and by-products by fermentation', in *Bioresource Technology*, 63(1):75-9.
Kim, C. and Curry, J. (1993) 'Fordism, flexible specialization and agri-industrial restructuring', in *Sociologia Ruralis*, XXXIII(1):61-80.
Kim, W. and Mauborgne, R. (1997) 'Value innovation', in *Harvard Business Review*, January-February:103-12.
King, J. (1997) 'The biotechnology revolution: self-replicating factories and the ownership of life forms', in J. Davis, T. Hirschl and M. Stack (eds) *Cutting Edge*, London: Verso.
Kleiner, K. (1997) 'Fields of genes', in *New Scientist*, 2095:4.
Kline, R. (1995) 'Constructing "technology" as "applied science"', in *Isis*, 86:194-221.
Kline, R. and Pinch, T. (1996) 'Users as agents of technological change: the social construction of the automobile in the rural United States', in *Technology and Culture*, 37(4):763-95.
Kleinman, D. (1998) 'Untangling context: understanding a university laboratory in the commercial world', in *Science, Technology & Human Values*, 23(3):285-314.
Kloppenburg, J. (1988) *First the Seed: The Political Economy of Plant Biotechnology 1492-2000*, Cambridge: Cambridge University Press.
KNAW (1996) *Technology Top Institutes: Report on the Scientific Assessment at the End of Phase 1*, Amsterdam: Royal Academy of Arts and Sciences.
Knights, D. and Willmott, H. (1997) 'The hype and hope of interdisciplinary management studies', in *British Journal of Management*, 8:9-22.
Knorr, D. (1987) 'Food biotechnology: its organization and potential', in *Food Technology*, 41(4):95-100.
Kobayashi, A. (1994) 'Coloring the field: gender, "race," and the politics of fieldwork', in *The Professional Geographer*, 46(1):73-9.

Kotabe, M. and Scott Swan, K. (1995) 'The role of strategic alliances in high technology new product development', in *Strategic Management Journal*, 16: 621-36.
Kraft, N. (1998) 'Breaking through the tape', in *Chemistry & Industry*, 7:250-2.
Kranakis, E. (1990) 'Technology, industry, and scientific development', in T. Frängsmyr (ed.) *75th Nobel Symposium, Solomon's House Revisited: The Organization and Institutionalization of Science*, Canton, Mass.: Science History Publications.
Krugman, P. (1996) *Pop Internationalism*, Cambridge, Mass.: MIT Press.
Kuhn, T. (1970) *The Structure of Scientific Revolutions*, (2nd edition, first published in 1962), Chicago: University of Chicago Press.
Kumar, K. (1995) *From Post-Industrial to Post-Modern Society: New Theories of the Contemporary World*, Cambridge, Mass.: Blackwell.
Kwaak van der, R. and Hersbach, G. (eds) (1993) *Biotech Opportunities in Europe: Establishing and Operating a Health Care Biotech Venture*, Amsterdam: Publimarket Communications Management.
Lagendijk, A. (1998) 'Regional institutions and knowledge - tracking new forms of regional development policy', paper presented at the Institute of British Geographers annual conference, Guilford, 6 January 1998.
Laidler, K. (1997) *To Light Such a Candle*, Oxford: Oxford University Press.
Lakatos, I. (1968) *The Problem of Inductive Logic*, Amsterdam: North Holland.
Lane, C. and Bachmann, R. (1996) 'The social constitution of trust: supplier relations in Britain and Germany', in *Organization Studies*, 17(3):365-95.
Lash, S and Urry, J. (1987) *The End of Organized Capitalism*, Cambridge: Polity Press.
Lash, S and Urry, J. (1994) *Economies of Signs & Spaces*, London: Sage.
Latour, B. (1986) 'The powers of association', in J. Law (ed.) *Power, Action and Belief: A New Sociology of Knowledge?*, London: Routledge.
Latour, B. (1987) *Science in Action*, Cambridge, Mass.: Harvard University Press.
Latour, B. (1991) 'Technology is society made durable', in J. Law (ed.) *A Sociology of Monsters: Essays on Power, Technology and Domination*, London: Routledge.
Latour, B. (1993) *We Have Never Been Modern*, New York: Harvester Wheatsheaf.
Latour, B. (1996) *Aramis: Or the Love of Technology*, Cambridge, Mass.: Harvard University Press.
Latour, B. (1997a) 'On actor-network theory: a few clarifications', paper presented at the *Actor Network and After* workshop, July 1997, internet document, http:/www.keele.ac./depts/stt/cstt2/ant/latour.htm.
Latour, B. (1997b) 'On recalling ANT', paper presented at the *Actor Network and After* workshop, July 1997, internet document, http:/www.keele.ac./depts/stt/cstt2/ant/latour.htm.
Laudan, R. (1995) 'Natural alliance or forced marriage? Changing relations between the histories of science and technology', in *Technology and Culture*, 36(2):17-28.
Law, J. (1988) 'The anatomy of a socio-technical struggle: the design of the TSR2', in B. Elliot (ed.) *Technology and Social Progress*, Edinburgh: Edinburgh University Press.
Law, J. (1994) *Organizing Modernity*, Oxford: Blackwell.
Law, J. (1997a) 'Topology and the naming of complexity', internet document (Centre for Social Theory and Technology [CSTT], Keele University), http://www.keele.ac.uk/depts/stt/staff/jl/pubs-JL3.htm.

Law, J. (1997b) 'Traduction/Trahison: notes on ANT', internet document (Centre for Social Theory and Technology [CSTT], Keele University) at http://www.keele.ac.uk/depts/stt/staff/jl/pubs-JL2.htm.
Lawrie, S. (1997) *Private Correspondence.*
Layton, E. (1976) 'Technology as knowledge', in *Technology and Culture*, 15(1): 31-41.
Lee, N. (1994) 'Child protection investigations: discourse analysis and the management of incommensurability', in *Journal of Community & Applied Social Psychology*, 4:275-86.
Lee, N. and Brown, S. (1994) 'Otherness and the actor network: the undiscovered continent', in *American Behavioural Scientist*, 37:772-90.
Lee, R. (1997) 'Economic geographies: representations and interpretations', in R. Lee and J. Wills (eds) *Geographies of Economies*, London: Arnold.
Lee, R. and Wills, J. (1997) *Geographies of Economies*, London: Arnold.
Lehmann, V. (1998) 'Patent on seed sterility threatens seed saving', in *Biotechnology and Development Monitor*, 35:6-8.
Leng, C., El-Hamamsy, L., Fleming, J., Fujiki, N., Keyeux, G., Knoppers, B. and Macer, D. (1995) 'Bioethics and human population genetics research', in *Proceedings of the Third Session of the International Bioethics Committee of UNESCO*, Vol. I, Paris: UNESCO.
Levidow, L. (1996) 'Stimulating mother nature, industrializing agriculture', in G. Robertson, M. Mash, L. Tickner, J. Bird, B. Curtis and T. Putnam (eds) *FutureNatural*, London: Routledge.
Levidow, L., Carr, S., Wield, D. and von Schomberg, R. (1997) 'European biotechnology regulation: framing the risk assessment of a herbicide-tolerant crop', in *Science, Technology and Human Values*, 22(4):472-505.
Leyshon, A. (1997) 'True stories? Global dreams, global nightmares, and writing globalization. Introduction to Section Two', in R. Lee and J. Wills (eds) *Geographies of Economies*, London: Arnold.
Lipietz, L. (1987) *Mirages and Miracles*, London: New Left Books.
Livingstone, D. (1992) *The Geographical Tradition*, Oxford: Blackwell.
Llewelyn, J. (1988) 'The second generation of enzymes', in R. Greenshields (eds) *Resources and Applications of Biotechnology*, London: Macmillan.
Lovitt, W. (1977) 'Introduction', in M. Heidegger (1977) *The Question Concerning Technology*, New York: Harper & Row.
Lowe, J. and Taylor, P. (1996) 'The role of complementary assets in technology strategy', in A. Belcher, J. Hassard and S. Procter (eds) *R&D Decisions: Strategy, Policy and Innovations*, London: Routledge.
Luke, T. (1997) 'At the end of nature: cyborgs, 'humachines' and environments in postmodernity', in *Environment and Planning A*, 29:1367-80.
Lundvall, B. (ed.) (1992) *National Systems of Innovation*, London: Pinter.
Lyotard, J-F. (1993) *The Postmodern Condition: A Report on Knowledge* (2nd edition, first published in 1979), Minneapolis: University of Minnesota Press.
Macer, D. (1996) *Food, Plant Biotechnology and Ethics*, draft report for the fourth session of the International Bioethics Committee, 3 and 4 October 1996, Paris: UNESCO.
Macintyre, S. (1995) 'The public understanding of science or the scientific understanding of the public? A review of the social context of the 'new genetics', in *Public Understanding of Science*, 4:223-32.
MacKenzie, D. (1992) 'Economic and sociological explanations of technical change', in R. Coombs, P. Saviotti and V. Walsh (eds), *Technological Change and*

Company Strategies: Economic and Sociological Perspectives, London: Harcourt Brace Jovanovich.
MacKenzie, D. and Wajcman, J. (1996) 'Introductory essay', in D. MacKenzie and J. Wajcman (eds) *The Social Shaping of Technology*, Milton Keynes: Open University Press.
Madden, D. (1995) *Food Biotechnology: An Introduction*, Washington: International Life Sciences Institute Press.
MAFF (1994) *Food Sense fact sheet, No. 2*, London: Ministry of Agriculture, Fisheries and Food.
Magnien, E. and de Nettancourt, D. (1993) *What drives European biotechnology research? IJTM Special Publication on the Management of Biotechnology*, London: Interscience Enterprises Ltd.
Mahler, J. (1996) 'The Danish model - achieving public confidence and acceptance', in B. Marshall and F. Miller (eds) *Biotechnologies in Agriculture and Food - Coming to the Market*, Reading: Centre for Agricultural Studies.
Malecki, E. (1997) *Technology & Economic Development*, Harlow: Longman.
MANMF (1995) *Regulation of Genetically Modified Organisms*, The Hague: Ministry of Agriculture, Nature Management and Fisheries.
Mannion, A. (1995) 'Agriculture, environment and biotechnology', in *Agriculture, Ecosystems and Environment*, 53:31-45.
Mannion, A. (1997) 'Agriculture and land transformation. 2. Present trends and future prospects', in *Outlook on Agriculture*, 26(3):151-8.
Marcuse, H. (1986) *One-Dimensional Man*, London: Ark Paperbacks.
Margolis, J. and Duyk, G. (1998) 'The emerging role of the genomics revolution in agricultural biotechnology', in *Nature biotechnology*, 16(4):311.
Marlier, E. (1992) 'Eurobarometer 35.1: opinions of Europeans on biotechnology in 1991', in J. Durant (ed.) *Biotechnology in Public: A Review of Recent Work*, London: Science Museum.
Marks, L. (1993) 'Biotechnology', in P. Johnson (ed.) *European Industries: Structure, Conduct, and Performance*, Aldershot, Hants: Elgar.
Marshall, B. and Miller, F. (eds) (1996) *Biotechnologies in Agriculture and Food - Coming to the Market*, Centre for Agricultural Strategy (CAS) paper 34, Reading: Centre for Agricultural Strategy (CAS).
Martin, E. (1996) 'Citadels, rhizomes, and string figures', in S. Aronowitz, B.
Martinsons and M. Menser (eds) (1996) *technoscience and cyber culture*, New York: Routledge.
Marx, L. and Smith, M. (1994) 'Introduction', in M. Smith and L. Marx (eds) *Does Technology Drive History? The Dilemma of Technological Determinism*, Cambridge, Mass.: MIT Press.
Maryanski, J. (1990) 'Special challenges of novel foods (biotechnology)', in *Food Drug Cosmetic Journal*, 45(5):545-50.
Massey, D. and Wield, D. (1992) 'Science parks: a concept in science, society, and 'space' (a realist tale)', in *Environment and Planning D: Society and Space*, 10: 411-22.
Massey, D., Quintas, P. and Wield, D. (1992) *High-tech Fantasies: Science Parks in Society, Science and Space*, London: Routledge.
Massey, D. (1997) 'Economic/non-economic', in R. Lee and J. Wills (eds) *Geographies of Economies*, London: Arnold.
Mayr, E. (1988) 'Darwin, intellectual revolutionary', in J. Hatton and P. Plouffe (eds) *The Culture of Science: Essays and Issues for Writers*, New York: MacMillan Publishing Company.

Mazur, B. (1995) 'Commercializing the products of plant biotechnology', in *Trends in Biotechnology*, 13:319-23.
McDowell, L. (1992) 'Valid games? A response to Erica Schoenberger', in *The Professional Geographer*, 44(2):212-5.
McDowell, L. and Court, G. (1994) 'Performing work: bodily representations in merchant banks', in *Economic Geography*, 70(3):229-51.
McDowell, L. (1997) 'A tale of two cities? Embedded organizations and embodied workers in the City of London', in R. Lee and J. Wills (eds) *Geographies of Economies*, London: Arnold.
McElroy, D. (1996) 'The industrialization of plant transformation', in *Nature biotechnology*, 14(6):715-6.
McKelvey, M. (1996) *Evolutionary Innovations: The Business of Biotechnology*, Oxford: Oxford University Press.
MEA (1994) *Biotechnology in the Netherlands: The Network Approach*, The Hague: Netherlands Ministry of Economic Affairs.
MEA (1995a) *Knowledge in Action: Knowledge and Know-how in the Dutch Economy*, The Hague: Netherlands Ministry of Economic Affairs.
MEA (1995b) *Biotechnology in the Netherlands: Ready for the Market*, The Hague: Netherlands Ministry of Economic Affairs.
MEA (1996) *Op weg naar Technologishe Topinstituten: Commissie van Wijzen, 25 September 1996*, The Hague: Netherlands Ministry of Economic Affairs.
Meagher, K. (1990) 'Institutionalising the bio-revolution: implications for Nigerian smallholders', in *The Journal of Peasant Studies*, 18(1):68-89.
MECS (1992) *Research and Development in The Netherlands*, The Hague: Netherlands Ministry of Education, Culture and Science.
Menser, M. and Aronowitz, S. (1996) 'On cultural studies, science and technology', in S. Aronowitz, B. Martinsons and M. Menser (eds) *technoscience and cyber culture*, New York: Routledge.
Michael, A. (1997) 'EU food labelling bonanza', in *Nature biotechnology*, 15(9):836.
Michael, M. and Grinyer, A. and Tiller, J. (1997) 'Teaching biotechnology: identity in the context of ignorance and knowledgeability', in *Public Understanding of Science*, 6:1-17.
Miller, D. (1994) *Modernity: An Ethnographic Approach. Dualism and Mass Consumption in Trinidad*, Oxford: Berg.
Miller, H. and Flamm, E. (1993) 'Biotechnology and food regulation', in *Current Opinion in Biotechnology*, 4:265-8.
Miller, R. (1984) *Analyzing Marx: Morality, Power and History*, Princeton, New Jersey: Princeton University Press.
Miller, R., Hobday, M., Leroux-Demers, T. and Olleros, X. (1995) 'Innovation in complex systems industries: the case of flight simulation', in *Industrial and Corporate Change*, 4 (2):363-400.
Millstone, E., Brunner, E. and White, I. (1994) 'Plagiarism or protecting public health', in *Nature*, 371:647-8.
Mitcham, C. (1994) *Thinking through Technology: The Path between Engineering and Philosophy*, Chicago: The University of Chicago Press.
Mitchell, J. (1983) 'Case and situation analysis', in *Sociological Review*, 31(2):187-211.
Le Monde (1996) 'Risques et promesses des plantes modifiées par la génétique', 24 October 1996:5.
Morgan, K. and Murdoch, J. (1998) 'Knowing networks: knowledge, power and innovation in the food chain', paper presented at *Capitalising on Knowledge*

Session at the Royal Geographical Society/Institute of British Geographers annual conference, Guilford, January 1998.
Morris, T. and Westbrook, R. (1996) 'Technical innovation and competitive advantage in retail financial services: a case study of change and industry response', in *British Journal of Management*, 7:45-61.
Morton, O. (1995) 'Unshackled: biotechnology and genetics', in *The Economist: A Survey of Biotechnology and Genetics*, 25 February 1995.
Moser, A. (1994) 'Trends in biotechnology. Sustainable technology development: from high tech to eco tech', in *Acta Biotechnologica*, 14(4):315-35.
Mostyn, B. (1985) 'The content analysis of qualitative research data: a dynamic approach', in M. Brenner, J. Brown and D. Canter (eds) *The Research Interview: Uses and Approaches*, London: Academic Press.
Motluk, A. (1998) 'Gene police could end up on the bean beat', in *New Scientist*, 2119:5.
Munton, R., Marsden, T. and Whatmore, S. (1990) 'Technological change in a period of agricultural adjustment', in P. Lowe, T. Marsden and S. Whatmore (eds) *Technological Change and the Rural Environment*, London: David Fulton Publishers.
Munton, R. (1992) 'The uneven development of capitalist agriculture: the repositioning of agriculture within the food system', in R. Hoggart (ed.) *Agricultural Change, Environment and Economy: Essays in Honour of W. B. Morgan*, London: Mansell.
Murdoch, J. (1994) *Weaving the Seamless Web: A Consideration of Network Analysis and its Potential Application to the Study of the Rural Economy*, Centre for Rural Economy Working Paper 3, Newcastle: University of Newcastle upon Tyne.
Murdoch, J. (1995) 'Actor-networks and the evolution of economic forms: combining description and explanation in theories of regulation, flexible specialisation, and networks', in *Environment and Planning A*, 27:731-57.
Murdoch, J. and Marsden, T. (1995) 'The spatilization of politics: local and national actor-spaces in environmental conflict', in *Transactions of the Institute of British Geographers*, 20(3):368-80.
Murdoch, J. (1997) 'Inhuman/nonhuman/human: actor-network theory and the prospects for a nondualistic and symmetrical perspective on nature and society', in *Environment and Planning D: Society & Space*, 15(6):731-56.
NABC (1991) *Agricultural Biotechnology at the Cross-Roads*, NABC Report 3, Ithaca, New York: National Agricultural Biotechnological Council.
NABC (1992) *Agricultural Biotechnology: Opportunities & Challenges*, NABC Report 4, Ithaca, New York: National Agricultural Biotechnological Council.
NABC (1995) *Genes for the Future: Discovery, Ownership, Access*, NABC Report 7, Ithaca, New York: National Agricultural Biotechnological Council.
Nandy, A. (1988) *Science, Hegemony and Violence: A Requiem for Modernity*, Delhi: Oxford University Press.
Nature biotechnology (1996) 'Is British Biotech's Marimastat a major cancer drug?', 14(7):819.
Nature biotechnology (1997a) 'Novartis' role in 21st century drug development', 15(6):485.
Nature biotechnology (1997b) 'Food foments European disunity', 15(13):1317.
Nature biotechnology (1997c) 'EuropaBio's regulatory niche', 15(8):693.
Nature biotechnology (1997d) 'Hoechst/TKT fight Amgen suit', 15(7):601.
Nature biotechnology (1997e) 'IP's shifting sands', 15(5):393.
Nature biotechnology (1997f) '716 companies, 1 cloned sheep', 15(6):490.

Nature biotechnology (1998a) 'Gist antibiotic plant follows acquisition', 16(4):315.
Nature biotechnology (1998b) 'Japan to abandon genetic engineering labels', 16(2): 121.
Nature biotechnology (1998c) 'Cargill seeds sold', 18(8):703.
NCCPB (1994) *UK National Consensus Conference on Plant Biotechnology*, 2-4 November 1994, Tuke Hall, Regents College, London.
NEDC (1991) *New Life for Industry: Biotechnology, Industry and the Community in the 1990s and Beyond*, report prepared and published by the National Economic Development Council, London: NEDC.
Nelson, R. and Winter, S. (1977) 'In search of useful theory of innovation', in *Research Policy*, 6:37-76.
Nelson, R. and Winter, S. (1982) *An Evolutionary Theory of Economic Change*, Cambridge, Mass: Harvard University Press.
Newell, S. and Swan, J. (1995) 'Professional associations as important mediators of the innovation process', in *Science Communications*, 16(4): 371-87.
NFIA (1995) *Biotechnology in the Netherlands*, The Hague: Netherlands Foreign Investment Agency.
Nielson, T. (1997) 'Behind the color code of "no"', in *Nature biotechnology*, 15(13): 1320-1.
Nitin, N. (1992) *Networks and Organisations*, Cambridge, Mass.: Harvard Business School Press.
Novo Nordisk (1995) *Annual Report*, Copenhagen: Novo Nordisk.
Oakley, A. (1981) 'Interviewing women: a contradiction in terms', in W. Roberts (ed.) *Doing Feminist Research*, London: RKP.
Observer (1996) 'Sick secret of a 'healthy' diet', 28 April 1996:15.
OECD (1981) *The Measurement of Scientific and Technical Activities, Frascati Manual*, Paris: Organization for Economic Co-operation and Development.
OECD (1989) *Biotechnology: Economic and Wider Impacts*, Paris: Organization for Economic Co-operation and Development.
OECD (1992) *Biotechnology, Agriculture and Food*, Paris: Organization for Economic Co-operation and Development.
Omta, S. (1996) *Critical Success Factors in Biomedical Research and Pharmaceutical Innovation*, Dordrecht: Kluwer Academic Publishers.
Oppenheim, A. (1992) *Questionnaire Design, Interviewing and Attitude Measurement*, London: Pinter Publishers.
Osborn, R. and Hagedoorn, J. (1997) 'The institutional and evolutionary dynamics of interorganizational alliances and networks', in *Academy of Management Journal*, 40(2):261-78.
Otero, G., Scott, S. and Gilbreth, C. (1997) 'New technologies, neoliberalism and social polarization in Mexico's agriculture', in J. Davis, T. Hirschl and M. Stack (eds) *Cutting Edge*, London: Verso.
Pal, A. (1992) 'Technology profile: biocatalysis', *TechMonitoring*, March 1992, London: SRI International.
Patel, P. and Pavitt, K. (1994) 'National innovation systems: why they are important and how they might be measured and compared', in *Economics of Innovation and New Technology*, 3:77-95.
Pendick, D. (1997a) 'Clones unlimited', in *New Scientist*, 2095:11.
Pendick, D. (1997b) 'The smallest builders in the world', in *New Scientist*, 2098:34-7.
Pepper, D. (1996) *Modern Environmentalism*, London: Routledge.
Perez, C. (1983) 'Structural change and the assimilation of new technologies in the economic and social system', in *Futures*, 15(4):357-75.

Persley, G. and Peacock, W. (1993) 'Biotechnology for bankers', in G. Persley (ed.) *Agricultural Biotechnology: Opportunities for International Development*, London: Flamingo.
Peters, T. (1992) *Liberation Management: Necessary Disorganization for the Nanosecond Nineties*, London: MacMillan.
Peterson, J. (1989) 'Hormones, heifers and high politics - biotechnology and the common agriculture policy', in *Public Administration*, 67:455-71.
Pfost, D. (1998) 'The engineering of drug discovery', in *Nature biotechnology*, 16(4):313.
Pilnik, W. and Voragen, A. (1990) 'Use of enzymes in fodd processing', in *Food Biotechnology*, 4(1):319-28.
Pinch, T. and Bijker, W. (1987) 'The social construction of facts and artifacts: or how the sociology of science and the sociology of technology might benefit each other', in W. Bijker, T. Hughes and T. Pinch (eds) *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge, Mass.: MIT Press.
Piore, M. and Sabel, C. (1984) *The Second Industrial Divide: Possibilities for Prosperity*, New York: Basic Books.
Pitcher, W. (1986) 'Genetic modification of enzymes used in food processing', in *Food Technology*, October 86:62-9.
Poole, N. (1996) 'Development of a national and international biotechnology regulatory framework for agriculture and food', in B. Marshall and F. Miller (eds) *Biotechnologies in Agriculture and Food-Coming to the Market*, Reading: Centre for Agricultural Strategy, University of Reading.
Popper, K. (1968) *The Logic of Scientific Discovery*, London: Hutchinson.
Porter, M. (1990) *The Competitiveness of Nations*, New York: Free Press.
Poste, G. (1998) 'Molecular medicine and information-based targeted healthcare', in *Nature biotechnology*, 16, suppplement:19-21.
Praaning, D. (1996) 'Intelligence in enzyme regulation: promoting consumer confidence', in *Nature biotechnology*, 14:112.
Prevezer, M. and Toker, S. (1995) 'The degree of integration in strategic alliances in biotechnology', in *Technology Analysis & Strategic Management*, 8(2):117-33.
Price, B. (1995) *Biotechnology, Environment and Control*, a Financial Times Management Report, London: Financial Times.
Prout, A. (1996) 'Actor network theory, technology and medical sociology: an illustrative analysis of the metered-dose inhaler', in *Sociology of Health & Illness*, 18(2):198-219.
PWT (1996) *The Second Carousel: From Technology to Application*, internal document from the Advisory Commission on Biotechnology Public Information, Leiden: PWT.
Rabinow, P. (1996) *Making PCR: A Story of Biotechnology*, Chicago: University of Chicago Press.
Ramsay, J. (1998) 'Monsanto fights back', in *Chemistry & Industry*, 14:584.
Randle, K. and Currie, F. (1996) 'R&D strategy and the implications for management control', in A. Belcher, J. Hassard and S. Procter (eds) *R&D Decisions: Strategy, Policy and Innovations*, London: Routledge.
Redclift, M. and Benton, T. (eds) (1994) *Social Theory and the Global Environment*, London: Routledge.
Research Fortnight (1998) 'Government announces £1 billion for research', 22 July 1998.

Richards, P. and Ruivenkamp, G. (1996) 'New tools for conviviaility: society and biotechnology', in P. Descola and G. Pálsson (eds) *Nature and Society: Anthropological Perspectives*, London: Routledge.
Richards, S. (1987) *Philosophy & Sociology of Science: An Introduction*, Oxford: Basil Blackwell.
Robertson, G., Mash, M., Tickner, L., Bird, J., Curtis, B. and Putnam, T. (1996) 'Introduction', in G. Robertson, M. Mash, L. Tickner, J. Bird, B. Curtis and T. Putnam (eds) *FutureNatural*, London: Routledge.
Robson, C. (1993) *Real World Research*, Oxford: Blackwell.
La Roche (1992) *The Pocket Roche: A Visitors Guide to F.Hoffman-La Roche Ltd*, Basel: Roche.
Rogers, E. and Shoemaker, F. (1971) *Communication of Innovations*, New York: Free Press.
Roobeek, A. (1995) 'A core technology in a new techno-economic paradigm', in M. Fransman, G. Junne and A. Roobeek (eds) *The Biotechnology Revolution*, Oxford: Blackwell.
Root-Berstein, R. (1989) 'Science as a way of knowing', in J. Hatton and P. Plouffe (eds) *The Culture of Science*, New York: Macmillan.
Roush, R. and Shelton, A. (1997) 'Assessing the odds: the emergence of resistance to Bt transgenic plants', in *Nature biotechnology*, 15(9):816-7.
Russo, E. and Cove, D. (1995) *Genetic Engineering: Dreams and Nightmares*, Oxford: W.H Freeman.
Russell, A. (1997) 'Technology as Knowledge', in M. Talalay, C. Farrands and R. Tooze (eds) *Technology, Culture and Competiveness*, London: Routledge.
Russell, B. (1954) *The Scientific Outlook*, London: Allen & Unwin.
Russell, B. (1979) *A History of Western Philosophy*, London: Unwin Paperbacks.
Russell, E. (1994) 'Biotechnology - a look at the future', in *Food Manufacture*, December 1994:24-5.
Ruttan, V. (1996) 'What happened to technology adoption-diffusion research?', in *Sociologia Ruralis*, 36(1):51-73.
SAGB (1996) 'Patents: A Key to Biotechnology's Success', in *European BioNews*, July 1996:9.
Sartre, J. (1995) *Anti-Semite and Jew*, New York: Schocken Books.
Sayer, A (1992) *Method in Social Science*, (2nd edition, first published in 1984), London: Hutchinson University Library.
Scarbrough, H. and Corbett, J. (1992) *Technology and Organization: Power, Meaning and Design*, London: Routledge.
Schibeci, R., Barns, I., Kennealy, S. and Davison, A. (1997) 'Public attitudes to gene technology: the case of the MacGregor's® tomato', in *Public Understanding of Science*, 6:167-83.
Schiller, D. (1997) 'The information commodity: a preliminary view', in J. Davis, T. Hirschl and M. Stack (eds.) *Cutting Edge*, London: Verso.
Schneiderman, H. (1990) 'Planetary patriotism: sustainable agriculture for the future', in *Environmental Science Technology*, 24(4):466-73.
Schoenberger, E. (1991) 'The corporate interview as a research method in economic geography', in *The Professional Geographer*, 43(2):180-9.
Schoenberger, E. (1992) 'Self-criticism and self-awareness in research: a reply to Linda McDowell', in *The Professional Geographer*, 44(2):215-8
Schoenberger, E. (1997) *The Cultural Crisis of the Firm*, Oxford: Blackwell.
Schofield, J. (1993) 'Generalizability of qualitative research', in M. Hammersley (ed.) *Social Research: Philosophy, Politics and Practice*, London: Sage.

Schot, J. (1992) 'The policy relevance of the quasi-evolutionary model: the case of stimulating clean technologies', in R. Coombs, P. Saviotti and V. Walsh (eds) *Technological Change and Company Strategies*, London: Harcourt Brace Jovanovich.

Schumpeter, J. (1934) *The Theory of Economic Development*, Cambridge, Mass.: Harvard University Press.

Schumpeter, J. (1939) *Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process, Volumes I & II*, New York: McGraw-Hill.

Schumpeter, J. (1976) *Capitalism, Socialism and Democracy*, London: George Allen & Unwin.

Science Museum (1997) *Future Foods: An Exhibition Looking at Genetically Modified Foods*, 20 November 1997-29 March 1998, London: Science Museum.

Seitz, F. (1992) *The Science Matrix*, New York: Springer-Verlag.

Senior, I. and Dale, P. (1996) 'Plant transgene silencing - gremlin or gift?', in *Chemistry & Industry*, 19 August 1996:604-8.

Sennett, R. (1980) *Authority*, London: Faber and Faber.

Sharp, M. (1995) 'Applications of biotechnology: an overview', in M. Fransman, G. Junne and A. Roobeek (eds) *The Biotechnology Revolution*, Oxford: Blackwell.

Shohet, S. (1994) 'Painting UK biotech by numbers', in *BIO/TECHNOLOGY, EURO/FEATURE*, Autumn 1994:1-12.

Shohet, S. (1996) 'Biotechnology in Europe: contentions in the risk-regulating debate', in *Science and Public Policy*, 23:117-22.

Shore, B. and Venkatachalam, A. (1996) 'Role of national culture in the transfer of information technology', in *Journal of Strategic Information Systems*, 5:19-35.

Simmie, J. (1997a) 'Origins, structure and contents', in J. Simmie (ed.) *Innovations, Networks and Learning Regions*, London: Regional Studies Association.

Simmie, J. (1997b) 'The origins and characteristics of innovation in highly innovative areas: the case of Hertfordshire', in J. Simmie (ed.) *Innovations, Networks and Learning Regions*, London: Regional Studies Association.

Sinsheimer, R. (1983) 'Genetic engineering: life as a plaything', in J. Hatton and P. Plouffe (eds) *The Culture of Science: Essays and Issues for Writers*, New York: MacMillan Publishing Company.

Slappendel, C. (1996) 'Perspectives on innovation in organizations', in *Organization Studies*, 17(1):107-29.

Smith, G. (1996) *Nietzsche, Heidegger and the Transition to Postmodernity*, Chicago: University of Chicago Press.

Smith, K. (1996) 'New views of innovation and challenges to R&D policy' in A. Belcher, J. Hassard and S. Procter (eds) *R&D Decisions: Strategy, Policy and Disclosure*, London: Routledge.

Smith, J. (1994) 'New opportunities in food biotechnology', in *Food Australia*, 46(6):262-5.

Smith, M. (1994) 'Technological determinism in American culture', in M. Smith and L. Marx (eds) *Does Technology Drive History? The Dilemma of Technological Determinism*, Cambridge, Mass.: MIT Press.

Smith, N. (1990) *Uneven Development: Nature, Capital and the Production of Space* (2nd edition, first published in 1984), Oxford: Basil Blackwell.

Smith, N. (1996) 'The production of nature', in G. Robertson, M. Mash, L. Tickner, J. Bird, B. Curtis and T. Putnam (eds) *FutureNatural*, London: Routledge.

Smith, T. (1994) 'Commercial exploitation of transgenics', in *Biotechnology Advances*, 12:679-86.

Soper, K. (1996) 'Nature/'nature'', in G. Robertson, M. Mash, L. Tickner, J. Bird, B. Curtis and T. Putnam (eds) *FutureNatural*, London: Routledge.
Le Soir (1996) 'Le Génie Génétique', 21 November 1996:15.
Spinney, L. (1998) 'Check this out...can molecular tests reassure those who don't want to eat mad cows or engineered crops?', in *New Scientist*, 2119:5.
The Splice of Life (1997a) 'Bt maize: the facts', February 1997, 3(4):9.
Squier, S. (1998) 'Interspecies reproduction: xenographic desire and the feminist implications of hybrids', in *Cultural Studies*, 12(1):360-81.
Star, S. (1991) 'Power, technologies and the phenomenology of conventions: on being allergic to onions', in J. Law (ed.) *A Sociology of Monsters? Essays on Power, Technology and Domination, Sociological Review Monograph*, London: Routledge.
Steinberg, D. (1997a) 'Firms sleuth out transgenic foods', in *Nature biotechnology*, 15(13):1331.
Steinberg, D. (1997b) 'US biotechnology patent bids take a plunge', in *Nature biotechnology*, 15(12):1236.
Strange, S. (1988) *States and Markets: An Introduction to International Political Economy*, London: Pinter.
Strathern, P. (1997) *Crick, Watson & DNA*, London: Arrow Books.
Straughan, R. (1996) 'Ethical considerations', keynote paper presented at the *National Review Conference on Food and Modern Biotechnology*, 18 March 1996, London: The Food and Drink Federation.
Strohman, R. (1997a) 'The coming Kuhnian revolution in biology', in *Nature biotechnology*, 15(3):194-200.
Strohman, R. (1997b) 'Profit margins and epistemology', in *Nature biotechnology*, 15(12):1224-5.
Swan, J. and Newell, S. (1995) 'The role of professional associations in technology diffusions', in *Organization Studies*, 16 (5):847-874.
Swann, P. and Prevezer, M. (1996) 'A comparison of the dynamics of industrial clustering in computing and biotechnology', in *Research Policy*, 25(7):1139-57.
Tait, J. (1990) 'Environmental risks and the regulation of biotechnology', in P. Lowe, T. Marsden and S. Whatmore (eds) *Technological Change and the Rural Environment*, London: David Fulton Publishers.
Taverne, D. (1991) 'The new biotechnology in perspective', in *Science and Public Affairs*, 6(2):1-8.
Taylor, R. (1993) 'Expanding applications in the food industry for immobilized enzymes', in *Genetic Engineering News*, February 1:5.
Taylor, P. (1996) 'On the nation-state, the global, and social science', in *Environment and Planning A*, 28:1917-28.
Teece, D. (1988). 'Technological change and the nature of the firm', in G. Dosi, C. Freemen, R. Nelson, G. Silverberg and L. Soete (eds) *Technical Change and Economic Theory*, London: Pinter Publishers.
Teknologi-Rådet (1995) *Gensplejsede planter - regulering og anvendelse.* Rapport fra et ekspertseminar, Copenhagen: Teknologi-Rådet.
Terney, O. (1996) *20 år med genteknologi; Erfaringen og perspektiver*, Copenhagen: Foreningen af Bioteknologiske Industrier I Danmark.
Terranova, T. (1996) 'Posthuman unbounded: artificial evolution and high-tech subcultures', in G. Robertson, M. Mash, L. Tickner, J. Bird, B. Curtis and T. Putnam (eds) *FutureNatural*, London: Routledge.
Teuber, M. (1993) 'Genetic engineering techniques in food microbiology and enzymology', in *Food Reviews International*, 9(3):389-409.

Thomas, S. (1993) *Global Perspective 2010. The Case of Biotechnology*, a report for the FAST programme, Brussels: Commission of the European Communities.
Thomas, D. (1995) 'Nanotechnology's many disciplines', in *BIO/TECHNOLOGY*, 13(5):439-43.
Thrift, N. (1996) *Spatial Formations*, London: Sage.
Tiles, M. and Oberdiek, H. (1995) *Living in a Technological Culture*, London: Routledge.
Tils, C. and Sørup, P. (1997) 'Biotechnology as a clean production technology in pulp and paper', in *The IPTS Report*, 16:5-12.
Times (1994) 'Co-op tomato veto signals setback for gene-altered foods', 17 September 1994:9.
Tombs, M. (1990) *Biotechnology in the Food Industry*, Milton Keynes: Open University Press.
Toffler, A. (1980) *The Third* Wave, New York: William Morrow.
Tornatzky, L. and Fleischer, M. (1990) *The Processes of Technological Innovation*, Lexington, Mass.: Lexington Books.
Touraine, A. (1995) *Critique of Modernity*, Oxford: Blackwell Press.
Towalski, Z. and Rothman, H. (1995) 'Enzyme technology', in M. Fransman, G. Junne and A. Roobeek (eds) *The Biotechnology Revolution*, Oxford: Blackwell.
Traweek, S. (1988) *Beamtimes and Lifetimes: The World of High Energy Physicists.* Cambridge, Mass.: Harvard University Press.
Trigg, R. (1993) *Rationality & Science: Can it explain everything*, Oxford: Blackwell.
Turnbull, D. (1993) *Maps are Territories, Science is an Atlas*, Chicago: Chicago University Press.
Turner, B. (1995) 'Introduction: defining postmodernity', in B. Turner (ed.) *Theories of Modernity and Postmodernity*, London: Sage.
Turner, B. (1996) 'Introduction', in *The Blackwell Companion to Social Theory*, Oxford: Blackwell.
Utterback, J. and Abernathy, W. (1993) 'A dynamic model of process and product innovation', in *The International Journal of Management Science*, 6:639-56.
Vasil, I. (1996) 'Milestones in crop biotechnology - transgenic cassavas and agrobacterium-mediated transformation of maize', in *Nature Biotechnology*, 14:702-3.
Vattimo, G. (1988) *The End of Modernity*, Cambridge: Polity Press.
Vaucheret, H. and Tepfer, M. (1993) 'Continental drift: a European perspective on regulation in agricultural biotechnology', in *Current Opinion in Biotechnology*, 4:263-4.
Vazquez, A. (1977) *The Philosophy of Praxis*, London: Merlin Press.
Vergragt, P., Groenewegen, P. and Mulder, K. (1992) 'Industrial technological innovation: interelationships between technological, economic and sociological analyses', in R. Coombs, P. Saviotti and V. Walsh (eds) *Technological Change and Company Strategies: Economic and Sociological Perspectives*, London: Harcourt Brace.
Voragen, F. (1997) Private correspondence.
Wallerstein, I. (1990) 'Culture as the ideological battleground of the modern world-system', in M. Featherstone (ed.) *Global Culture*, London: Sage.
Walter, R. (1998) 'Consumer perspective', in *Resource Management in Challenged Environments*, NABC Report 9, Ithanca, New York: National Agricultural Biotechnology Council.
Ward, M. (1996) 'PGS-AgrEvo deal stirs up plant biotechnology', in *Nature biotechnology*, 14(10):1210.

Ward, M. (1997) 'European patent legislation bounces back', in *Nature biotechnology*, 14(13):1648.
Ward, N. (1994) *Farming on the Threadmill: Agricultural Change and Pesticide Protection*, unpublished PhD thesis, University of London.
Watson, J. (1968) *The Double Helix*, London: Penguin.
Waugh, P. (1992) 'Introduction', in P. Waugh (ed.) *Postmodernism: A Reader*, London: Edward Arnold.
Webb, K. (1995) *An Introduction to Problems in the Philosophy of Social Sciences*, London: Pinter.
Webster, A. (1991) *Science, Technology and Society*, London: MacMillan.
WEF (1997) *The Global Competitiveness Report, 1997*, Geneva: World Economic Foundation.
Weitzman, E. and Miles, M. (1995) *Computer Programmes for Qualitative Data Analysis*, London: Sage.
Whatmore, S. (1994) 'Global agro-food complexes and the refashioning of rural Europe', in A. Amin and N. Thrift (eds) *Globalization, Institutions and Regional Development in Europe*, Oxford: Oxford University Press.
Wheelwright, S. and Clark, K. (1992) *Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality*, New York: The Free Press.
Whipp, R. and Clark, P. (1986) *Innovation and the Auto Industry: Product, Process and Work Organizations*, London: Francis Pinter.
WHO (1991) *Strategies for Assessing Safety of Foods Produced by Biotechnology*, Geneva: World Health Organisation.
Wijk van, J. (1998) 'Plant patenting provision reviewed in WTO', in *Biotechnology and Development Monitor*, 34:6-9.
Wiktorowicz, M. and Deber, R. (1997) 'Regulating biotechnology: a rational-political model of policy development', in *Health Policy*, 40(2):115-38.
Wildavsky, A. (1991) 'Public policy', in B. Davis (ed.) *The Genetic Revolution: Scientific Prospects and Public Perceptions*, Baltimore: John Hopkins University Press.
Wilkie, T. (1996) 'Genes 'R' Us', in G. Robertson, M. Mash, L. Tickner, J. Bird, B. Curtis and T. Putnam (eds) *FutureNatural: Nature, Science, Culture*, London: Routledge.
Wilkins, A. (1996) 'Are there Kuhnian revolutions in biology', in *BioEssays*, 18:695-6.
Williamson, O. (1975) *Markets and Hierarchies: Analysis and Antitrust Implications*, New York: Free Press.
Winch, G. (1994) *Managing Production: Engineering, Change and Stability*, Oxford: Clarendon Press.
Winchester, H. (1996) 'Ethical issues in interviewing as a research method in human geography', in *Australian Geographer*, 2(1):117-31.
Winner, L. (1977) *Autonomous Technology: Technics-out-of Control as a Theme in Political Thought*, Cambridge, Mass.: MIT Press.
Winstanley, M. (1995) 'Inserting new genes into plants', in *Nutrition and Food Science*, 2 - March/April, 1995:27-30.
WIPO (1996) *Agreements Between the World Intellectual Property Orgnaization and the World Trade Organization*, Geneva: WIPO.
Woodward, J. (1965) *Industrial Organisation: Theory and Practice*, Oxford: Oxford University Press.
WTO (1994) *Agreement on the Application of Sanitary and Phytosanitary Measures*, World Trade Organisation internal document, Geneva: World Trade Organisation

WTO (1996) *Understanding the World Trade Organization Agreement on Sanitary and Phytosanitary Measures*, World Trade Organisation internal document, Geneva: World Trade Organisation.

Wymer, P. (1998) 'Genetically modified food: ambrosia or anathema?', in *Chemistry & Industry*, 11:422-4.

Wynne, B. (1992) *Public Understanding of Science - A Resume of Research.* Plenary paper to ESRC Biotechnology Joint Advisory Board Workshop, Cheltenham Park Hotel 20-21 October 1992.

Wynne, B. (1996) 'May the sheep safely graze? A reflexive view of the expert-lay knowledge divide', in S. Lash, B, Szerszynski and B. Wynne (eds) *Risk, Environment & Modernity*, London: Sage.

Yearley, S. (1997) 'The changing social authority of science', in *Science Studies*, 11(1):65-75.

Yin, R. (1994) *Case Study Research: Design and Methods*, London: Sage.

Zechendorf, B. (1994) 'What the public thinks about biotechnology', in *BIO/TECHNOLOGY*, 12:870-75.

Zilinskas, R. (1995) ' Biotechnology and the third world: missing link between research and applications', in M. Fransman, G. Junne and A. Roobeek (eds) *The Biotechnology Revolution*, Oxford: Blackwell.

Zimmerman, M. (1990) *Heidegger's Confrontation with Modernity*, Bloomington: Indiana University Press.

Zukin, S. and DiMaggio, P. (1990) *Structures of Capital: The Social Organization of the Economy*, Cambridge: Cambridge University Press.

Zukin, S. (1991) *Landscapes of Power: from Detroit to Disney World*, Berkeley, Ca.: University of California Press.